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OVERTURNING AND SLIDING ANALYSIS OF REINFORCED CONCRETE PROTECTIVE STRUCTURES

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FEBRUARY 1976

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This report presents design procedures and the computer program written to implement them for determining the gross motions of protective structures subjected to blast effects of high explosive detonations. These procedures are intended to supplement the design methods of the tri-service design manual "Structures to Resist the Effects of Accidental Explosions" (TM 5-1300).

The material presented includes dynamic analysis techniques for determining the gross motions of the structure on its supporting soil, methods for computing the time history of the blast load on the structure, and criteria and procedures

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Item 19. (continued)

Soil Properties
Computer Program
FORTRAN IV
Foundation Design
Soil Pressures
Ultimate Moment Capacity
Peak Applied Shears

Item 20. (continued)

for designing the foundation of the structure.

A system of classification of various soils is given together with a tabulation of critical soil properties.

Documentation of the computer program is provided by means of descriptions of the required input parameters, definitive illustrations of the coded input card formats, illustrations of input deck structures, the FORTRAN listing for the CDC 6600 computer, and sample problems.

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SUMMARY

This report was developed as a part of a program undertaken by the Manufacturing Technology Directorate of Picatinny Arsenal in recognition of the need for expanded design information pertaining to structures subjected to the blast environment due to accidental explosions within ammunition facilities. The purpose herein is to provide facility designers with procedures, and the computer program written to implement them, for determining the gross motions of protective structures on their supporting soils. The report is intended to supplement the design methods of the tri-service design manual "Structures to Resist the Effects of Accidental Explosions" (TM 5-1300).

Gross motions of the structure subjected to high intensity blast loads are determined using a technique which embodies the rigid body approximation to the structure's response in conjunction with a discrete element representation of the supporting soil. Non-linear soil behavior is considered in the analysis and incorporated into the computer program. The analysis is directed primarily towards cubicle-type structures but has application to other structure configurations.

A classification of various soils is provided together with representative values of critical soil properties for use in the computer program.

The computer program is presented in the form of program documentation, coded input card formats, input deck structures, FORTRAN listing for the CDC 6600 computer, and sample problems.

Detailed procedures are given for the computation of the time history of the blast loads on the structure, and the structural design of the foundations. Numerical examples are included to illustrate the procedures. Conclusions and recommendations are also presented.

CONCLUSIONS AND RECOMMENDATIONS

This report presents analysis techniques for predicting gross motions of structures, and design criteria and procedures for determining the size of the foundation base slab necessary to resist the soil pressure build-up beneath the structure during the response of the structure to the blast loads.

It is recommended that procedures and the computer program presented in this report be utilized in the design of blast-resistant protective structures for facilities engaged in the manufacture, maintenance, modification, inspection and storage of explosive materials.

SECTION 1

INTRODUCTION

1.1 Background

The design of facilities for the manufacture, maintenance, modification, inspection and storage of explosive materials utilizes special procedures and criteria in order to avoid mass detonations and explosive propagation in the event of an accidental explosion and to ensure protection for personnel and equipment. The basic design document in this area is the tri-service manual "Structures to Resist the Effects of Accidental Explosions" (TM 5-1300). This manual presents the procedures to quantitatively evaluate the ability of reinforced concrete structures to resist the effects of a detonation of high explosives. It provides procedures and the necessary data for the design of laced reinforced concrete elements which are required to resist close-in explosions.

Briefly, the methods in the manual treat the design of each blast-resistant element in a structure individually. These methods are based on the premise that the supports along the periphery of an element are completely fixed against translation and rotation and are capable of fully developing the strength of the element. Generally, this approach is adequate for the design of most protective structures.

In some design situations, however, an additional consideration, the motion of the protective structure or barrier on the supporting soil, must be included in the design process. This always occurs in the design of cantilever wall and single cell barriers which are isolated from surrounding structures (see Figures 1 and 2). These structures rely completely on the supporting soil to provide the needed resistance to the overturning and translational motions. Some protective barriers located within explosive storage and manufacturing facilities also fall into this category. An example of this is the cantilever wall barrier of Figure 3 which is placed in an existing facility. In this case, the existing foundation slab does not have sufficient strength or rigidity to support the wall. Therefore, a thick foundation, not integral with the base slab of the structure, is provided for the wall. Another example is the exterior blast wall of the structure shown in Figure 4. The entire resistance to overturning is provided by the foundation, as the side walls, shown in Figure 4, are not blast-resistant and therefore will fail. As a result, the wall can be expected to experience large overturning motions under the action of the blast. The excessive height of the wall will also add to the severity of

the overturning motions. In this case, buttress walls are added to restrain the exterior blast wall. In these situations, the overturning and/or translational motions of the protective structures or barriers may result in the propagation of the explosion or injury to personnel and, therefore, these motions must be considered in the design.

In contrast to the exterior wall shown in Figure 4, the interior blast-resistant dividing wall of the same structure is not susceptible to overturning as it is restrained by the foundation and the side walls (in the undamaged portion of the structure). In the multi-cell barrier of Figure 5, an explosion in one cell is confined by the blast-resistant walls and the overall structure is restrained from overturning by the massive walls and foundation slab. In these situations, the motion of the protective structure or barrier on the supporting soil is not a critical factor and, therefore, need not be considered in the design.

In this report, the procedures of TM 5-1300 have been extended to include analytical techniques to evaluate the motions of a structure on its supporting soil and methods and criteria to design those elements which prevent the structure from overturning and, if important, sliding.

The procedures and the computer program presented in this report were developed by the Manufacturing Technology Directorate of Picatinny Arsenal, with the assistance of Ammann & Whitney, Consulting Engineers, as part of the overall Picatinny Arsenal Safety Engineering Support Program for the U.S. Army Armament Command.

1.2 Objectives

The primary objective of this report is to present procedures and the computer program written to implement them for determining the gross motions of structures subject to the blast effects of high explosive detonations. These procedures are intended to supplement the design methods of TM 5-1300.

Secondary objectives include:

1. The presentation of procedures for determining the blast load history on the structure.

2. The presentation of representative values of critical soil properties for use in the computer program.

3. The presentation of criteria and procedures for designing foundations of protective structures subjected to large overturning and/or translational motions.

1.3 Format of the Report

The report is divided into three main parts. The first part, consisting of Sections 2, 3 and 4, is devoted to a description of the analysis technique utilized to compute the response of structures to time-dependent loadings and to the definition of the environments to which protective structures are subjected. In Section 2, the concept of rigid body analysis is introduced together with the equations of motion of the structure. Section 3 discusses quantitative procedures for computing the blast output of the explosives, while Section 4 presents the analytical methods utilized to simulate the behavior of soils under the dynamic motions of foundations. Included in the latter section are recommended values for critical soil properties to be used in the computer program.

The second part consists of Sections 5 and 6 and relates to the use of the computer program written to implement the procedures presented in earlier sections. Section 5 presents the capabilities of the computer program and a detailed description of the input requirements including input card formats and deck structures for the various options of the program. Section 6 describes in detail the computer program printed output and includes a discussion on the interpretation and utilization of the results as related to the design of foundations for protective structures.

The third part consists of the four appendices presented at the end of the report. The first three appendices present various quantitative procedures utilized in the performance of dynamic analyses of protective structures along with numerical examples which illustrate the use of these procedures. Appendix A contains the procedures for determining the impulse loads on foundation pads of cantilever wall barriers, resulting from the detonation of an explosive charge located outside the periphery of the structure. Appendix B presents the procedure for computing the arrival time and duration of blast pressures on a protective structure subjected to a close-in explosion. Appendix C contains criteria and procedures for designing the foundations and other elements which stabilize the structure against overturning. Appendix D contains the FORTRAN listing of the computer program for the CDC 6600 computer. Included in this appendix are samples of the punched card input data decks and the printed output of the program.

In order to simplify the overall presentation, most of the directly applicable material from TM 5-1300 has not been repeated in this report. As far as possible, applicable equations, design charts and tables and commentary material have been included herein by reference.

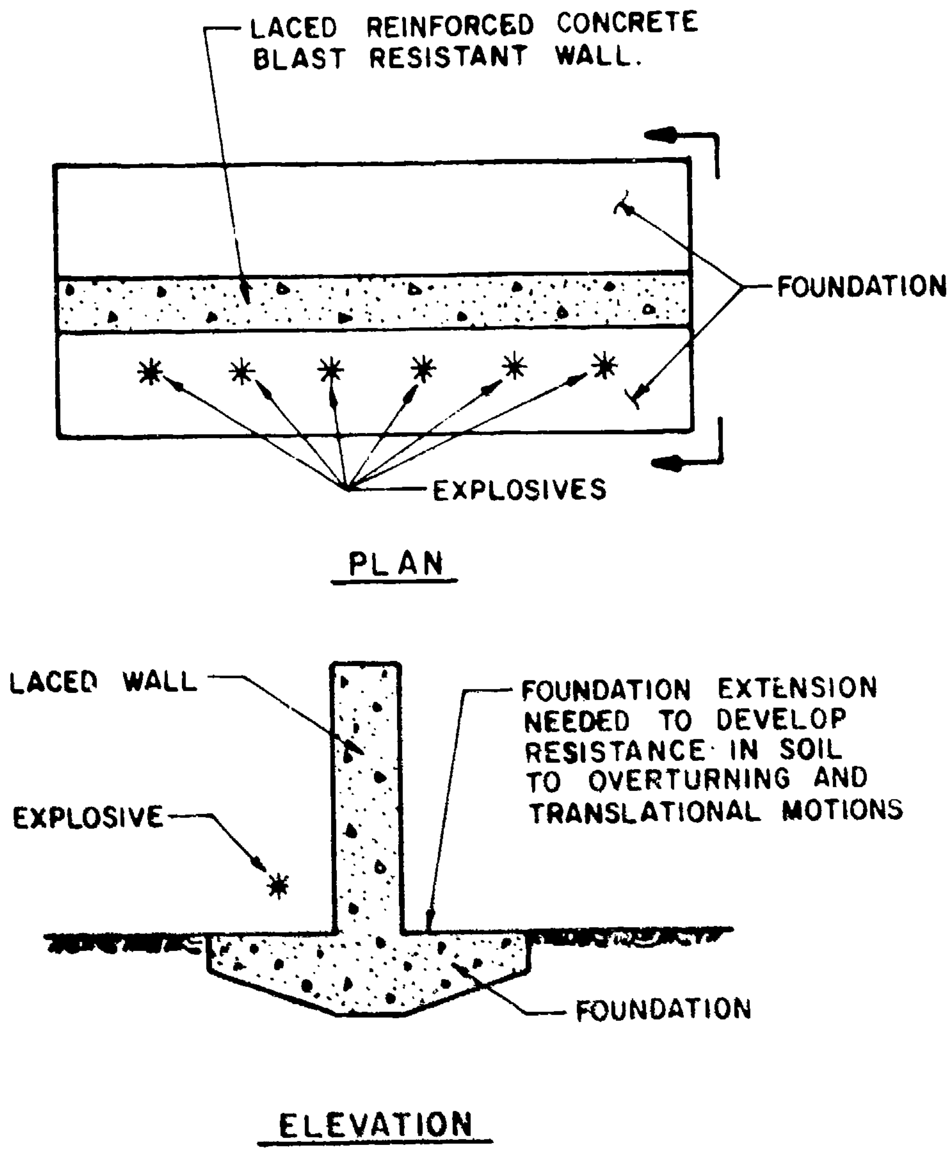


Figure 1. Cantilever wall barrier.

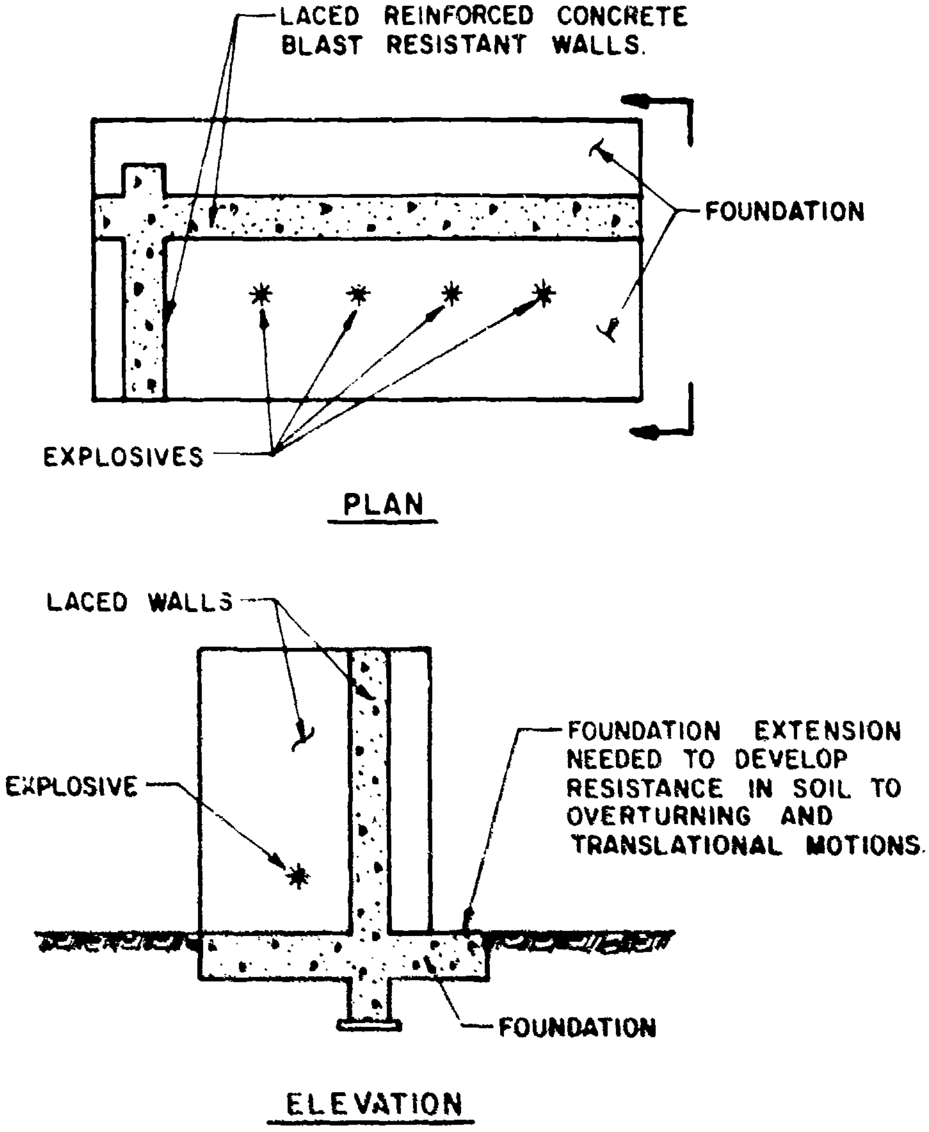


Figure 2. Two wall barrier.

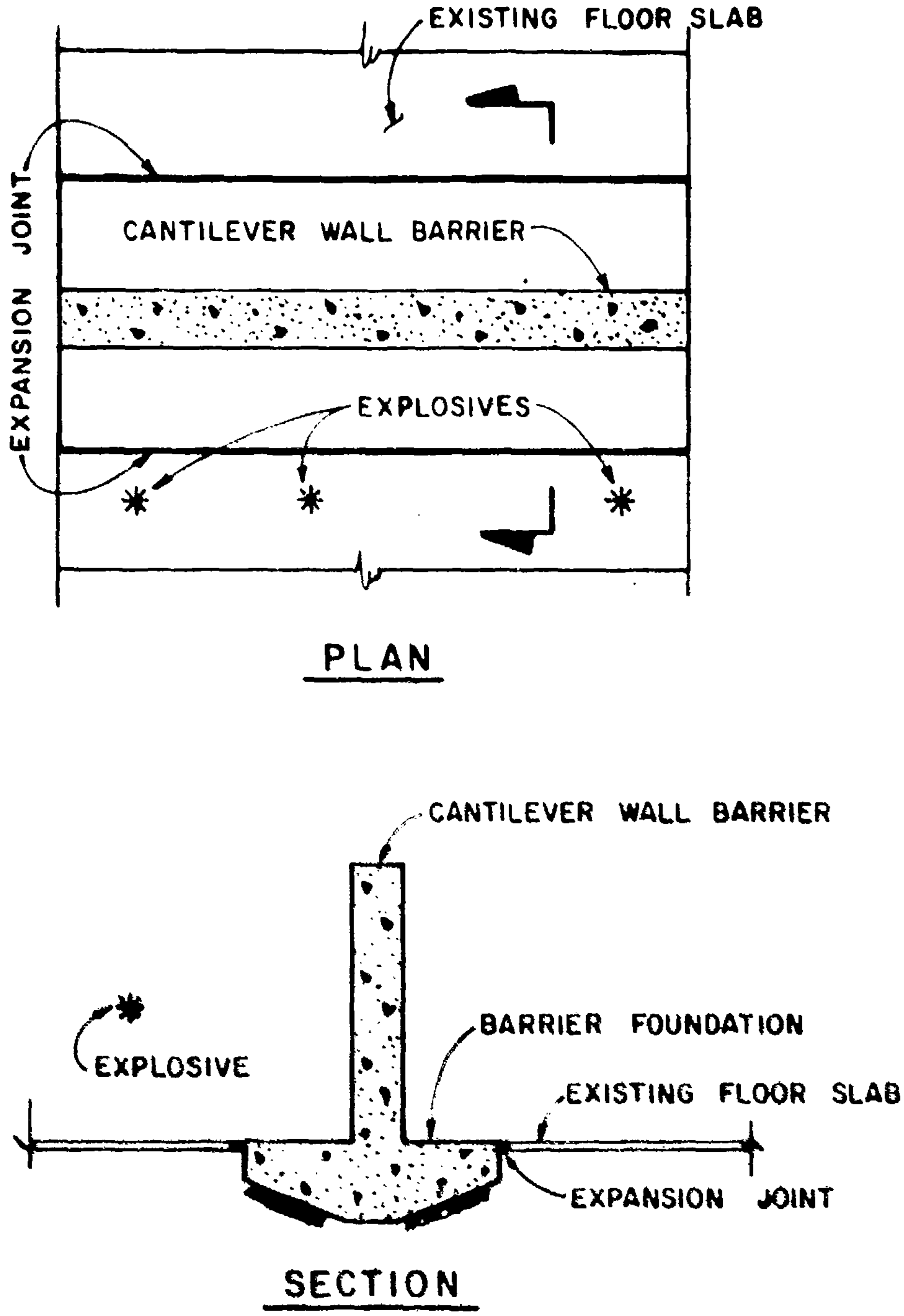


Figure 3. Cantilever wall barrier in existing facility.

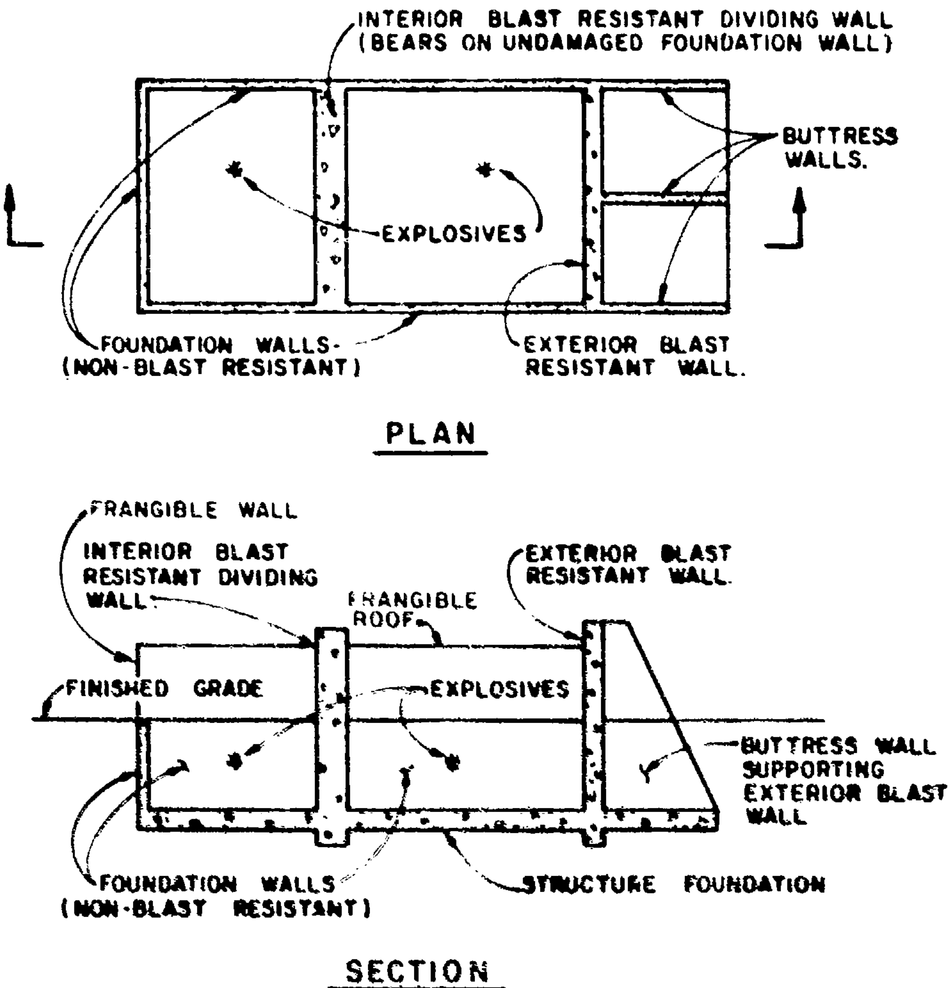


Figure 4. Cantilever wall barriers integral with larger structure.

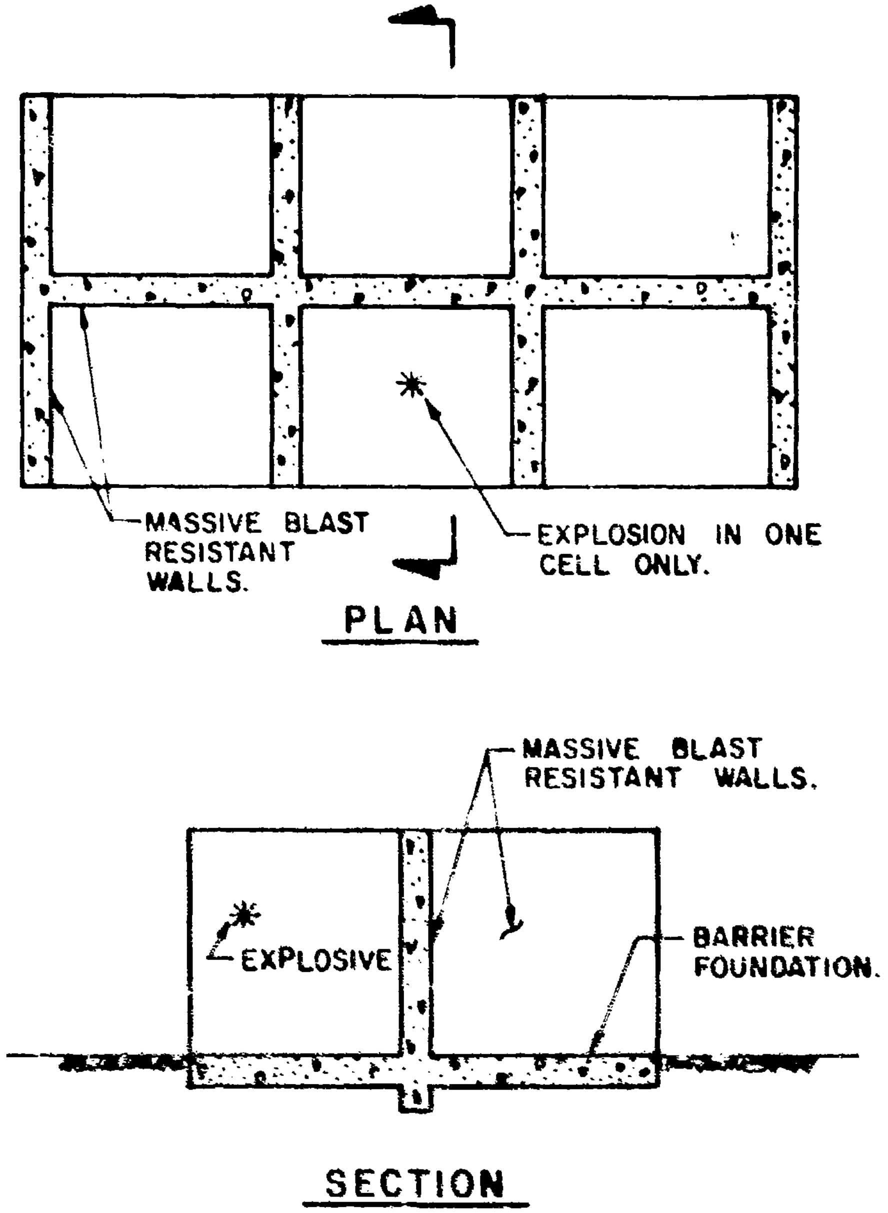


Figure 5. Multi-cell barricade.

SECTION 2

METHOD OF ANALYSIS

2.1 Introduction

The method of analysis for computing the gross motions of a protective structure subjected to the blast effects of a high explosive detonation is presented in this section. The response of the structure to the action of the blast is determined by performing a time-history dynamic analysis. The analysis considers the effect of the supporting soil on the response of the structure. A rigorous approach to this problem is exceedingly difficult and time consuming and, in fact, is not warranted since only the gross motions of the structure are required. Therefore, the problem is reduced to the simplest form possible but still retains the nonlinear complexity of the soil. This is accomplished utilizing the rigid body approximation. Briefly, this method treats the structure as a rigid body consisting of infinitely stiff elements. The blast loads and element inertial loads are assumed to act through the center of gravity of the structure. This reduces the response of the structure to the motion of the center of gravity and, therefore, greatly simplifies the computation.

The rigid body approach is well suited to the problem at hand. Generally, protective structures consist of massive laced concrete wall elements supported by equally massive foundation slabs resting on relatively soft soils. Consequently, the individual elements will usually reach their respective peak responses well before any significant motion of the foundation has occurred. As a result, there is usually little interaction between the individual responses of the elements and the gross response of the overall structure. Therefore, the rigid body analysis will generally produce reliable estimates of the gross motions of the structure without a severe overestimate of the response of the individual elements. The section that follows provides a more detailed discussion of the mechanics of the method and presents the equations of motion of the structure.

2.2 Equations of Motion

The structure is considered to be a rigid body constrained to move parallel to the x-y plane (see Figure 6). This condition is easily attained if we consider the x-y plane to be a plane of symmetry of the structure and the loading on the structure to be symmetrical about this plane. The mass and rotary inertia of the entire structure are lumped at the center of gravity. Blast pressures acting on the individual elements as well as the soil pressures acting on the foundation are transposed to the center of

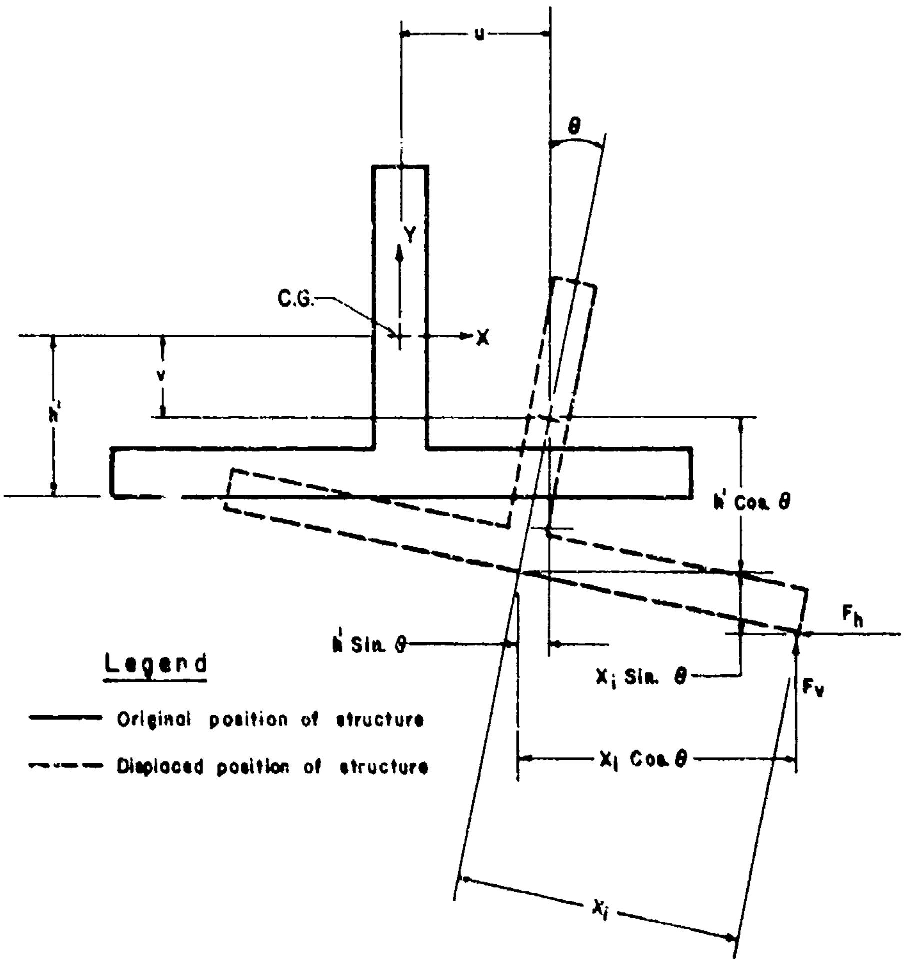


Figure 6. Displaced configuration of structure.

gravity. In this way, the response of the structure is reduced to three degrees of freedom. These are u, v and θ which are, respectively, the translations in the x and y axes and the rotation about the z axis.

The soil is represented analytically as a series of horizontal and vertical elements which resist the motion of the structure. The soil elements exhibit non-linear behavior. The total resistance developed in the soil at any time during the response is dependent on the displaced configuration of the foundation. A detailed discussion of the soil model is presented in Section 4.

The equations of motion for this system are listed below:

$$m\ddot{u} + R_h = H(t) \qquad (2.1)$$

$$m\ddot{v} + R_v = V(t) + mg \qquad (2.2)$$

$$I\ddot{\theta} + R_\theta = M(t) \qquad (2.3)$$

wherein:

$\ddot{u}$, $\ddot{v}$, $\ddot{\theta}$ = horizontal, vertical and rotational accelerations of the structure

m = mass of structure

I = mass moment of inertia of the structure about the z axis at the center of gravity

g = acceleration of gravity

$H(t)$ = resultant of horizontal blast loads at time t

$V(t)$ = resultant of vertical blast loads at time t

$M(t)$ = moment of resultant blast loads about the z axis at the center of gravity at time t

R_h = horizontal resistance of soil

R_v = vertical resistance of soil

R_θ = moment of horizontal and vertical soil resistance forces about the center of gravity.

The solutions for u, v and θ are readily obtained by numerically integrating the equations of motion utilizing the constant velocity procedure. This is a procedure by which the differential equations of motion are solved step by step, starting at zero time, when the displacement and velocity are presumably known. The time scale is divided into discrete intervals, and one progresses by successively extrapolating the displacement from one time station to the next. This procedure is well suited to the solution of non-linear problems since it allows for the inclusion of multi-linear resistance functions.

SECTION 3

BLAST LOADING

3.1 Introduction

This section presents the procedures for computing the load history for protective structures subjected to close-in explosions. The elements of the structure experience relatively high initial pressures which decay rapidly to zero. Definition of the loads for use in design of the individual elements is usually limited to the computation of the average impulse as the elements attain their peak responses long after the load acting on them has decayed to zero. However, the analysis method of Section 2, which employs numerical integration techniques, requires a complete definition of the load history. The load history is characterized by a peak pressure, an idealized pressure function and a duration. The quantities required to determine the load history are the average impulse, the time of arrival of the shock front and the duration of the blast pressures for each element of the structure. The idealized pressure function utilized is an initially peaked triangle defined by a peak pressure and a duration. Extensive studies of this simplified loading function have shown it to yield relatively accurate results in most applications. The peak pressures are computed using the aforementioned data. The total force on each surface is then calculated as a function of time and transposed to the center of gravity of the structure. Figure 7 illustrates the manner in which the blast load history is calculated. A more detailed description of the load history computation is provided in Section 5.3.3.

The procedures for computing the data required to determine the load history on the structure are discussed in the sections that follow.

3.2 Computation of Average Impulse

The computation of the impulse loads on the structure is outlined in Reference 1. This manual provides a systematic procedure to determine the impulse loads. The method is extremely tedious and requires extensive extrapolation and interpolation of the data. To facilitate the computation, a computer program was developed (Reference 2) which uses the quantity and location of the explosive and the geometry of the structure to determine the impulse load. Like the impulse data given in TM 5-1300, the "Impulse Program" can be used for computing the impulse loads on the walls and foundations of protective structures.

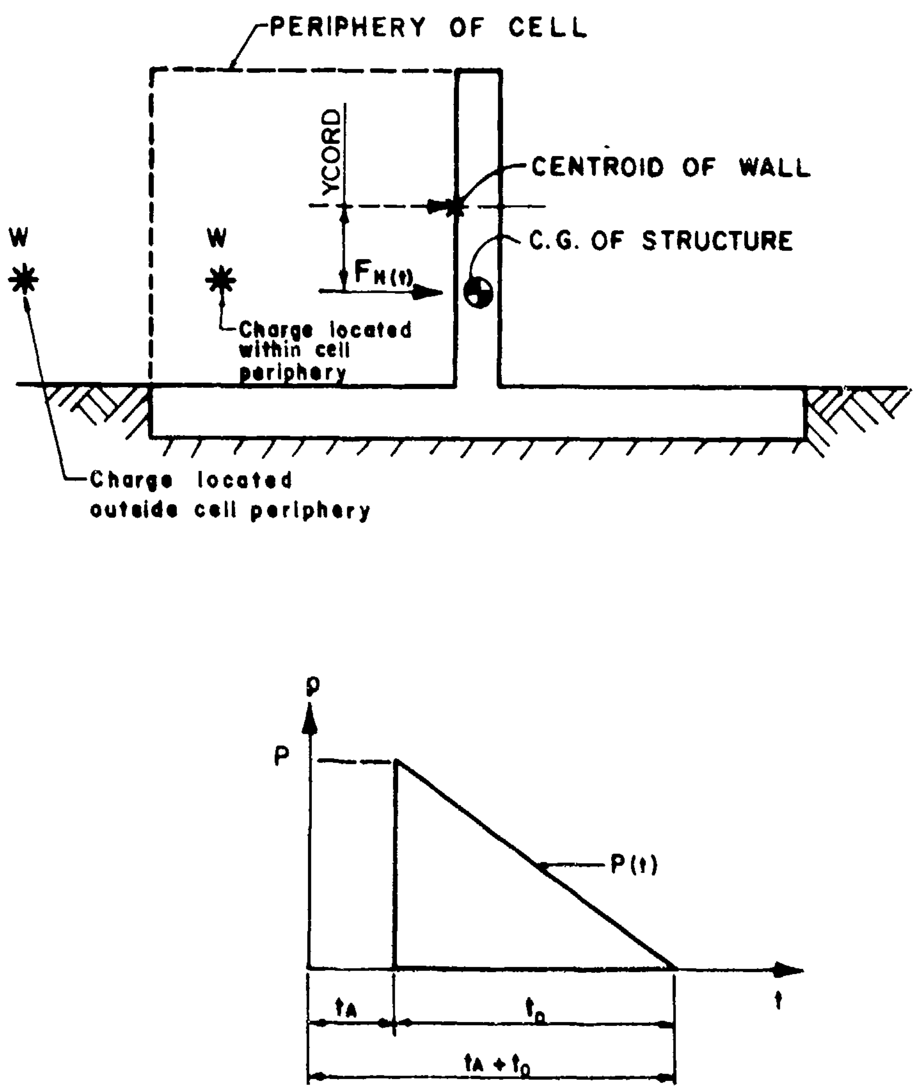


Figure 7. Blast load calculation.

The impulse data of Reference 1 is given in the form of charts which express the average scaled impulse (impulse per cube root of charge weight) as a function of the parameters which define the structure configuration, charge size and charge location. The charts contain the impulse loads for cantilever wall barriers and two-, three- and four-wall cubicles. The impulse charts and the "Impulse Program" were developed to compute the loads when the charge is located within the periphery of the cell. The case of a charge located outside of a cell was not included in the charts of Reference 1 nor considered in the development of the "Impulse Program". This situation rarely occurs in the design of cells, but it is not uncommon in the design of cantilever wall barriers. In this situation, the charts of Reference 1 and the "Impulse Program" can be utilized to determine the impulse on the cantilever wall but additional data is required to determine the impulse on the foundation.

In order to provide a means for determining the impulse loads on the foundations of cantilever wall barriers, additional impulse charts were prepared with a modified version of the "Impulse Program". The charts express the average scaled impulse as a function of the dimensions of the structure, charge weight and charge location. These additional impulse charts are presented in Appendix A.

Use of the impulse charts may require interpolation of the data in many cases. A procedure for interpolating the chart parameters is presented in Appendix A. The procedure is based on the methods presented in Section 4-10 of Reference 1. Included in the appendix is a sample problem which illustrates the use of the procedure.

3.3 Computation of Arrival Times and Load Duration

A large body of empirical data has been collected on the time of arrival of the blast front and the duration of the positive phase of the pressure wave. It has been determined that most blast parameters are scaled by the cube root of the charge weight for a given explosive. These parameters are thus presented in a scaled form, i.e., $t_A/W^{1/3}$, (t_A is the time of arrival) and $t_o/W^{1/3}$ (t_o is the duration of the positive phase) and plotted as functions of the scaled distance, $Z = R_A/W^{1/3}$, where R_A is the radial distance from the charge. Such correlation of data is found in Figure 4.5 of Reference 1 and reproduced in Figure B.1 of this report. To determine the arrival time or duration at a point of interest, one enters the curves of Figure B.1 with the given scaled distance and reads the parameter of interest from the appropriate curve.

The procedure for computing the arrival time of the blast wave and the duration of the load on those elements of the structure directly exposed to the blast is based on the methods (Section 4) and empirical data (Figure 4.5) presented in Reference 1. The procedure begins with the definition of the arrival time of the blast wave on an element ("t_A" in Figure 7) as the time required for the wave to arrive at the point on the element nearest to the explosive. An estimate of the load duration ("t_O" in Figure 7) is then obtained by computing an average time for the wave to fully engulf the element and adding this quantity to the average of the load durations at those points on the element farthest from the explosive (see Figure B.2). The times of arrival and load durations for the points of interest on the element are obtained from Figure B.1.

Appendix B presents an outline of the method and a sample application of it.

SECTION 4

SOIL - STRUCTURE INTERACTION

4.1 Introduction

This section presents the soil-structure interaction model for simulating the non-linear behavior of soils subjected to the dynamic motions of foundations. Included in the discussion is the relationship between the principal features of the model and the actual behavior of the soil. Following this is a system for classification of various soils and a tabulation of their respective properties for use in the interaction model.

The model is used in the dynamic analysis of protective structures. In the analysis, the model utilizes the motions of the foundation to determine the resisting forces in the soil. These forces are then substituted into the equations of motion presented in Section 2.

4.2 Soil Structure Interaction Model

The significant physical characteristics of the soil medium that are incorporated into the interaction model are:

1. The effect of a continuous supporting medium beneath the foundation.

2. The resistance to the downward and horizontal motions of the foundation. Both linear and bilinear resistance functions are included in the model.

3. The lack of rebound experienced when the foundation moves upward.

4. The effect of friction between the foundation and the soil.

The effect of the continuous medium is simulated by representing the soil as a series of discrete element pairs attached to the foundation at equally spaced intervals. Each pair consists of a horizontal and vertical element as shown in Figure 8. The resistance developed in each element at any time during the response is dependent upon the displacement of the foundation at the attachment point of the element. Generally, 10 to 15 pairs of elements are necessary to produce an adequate representation of a continuous medium.

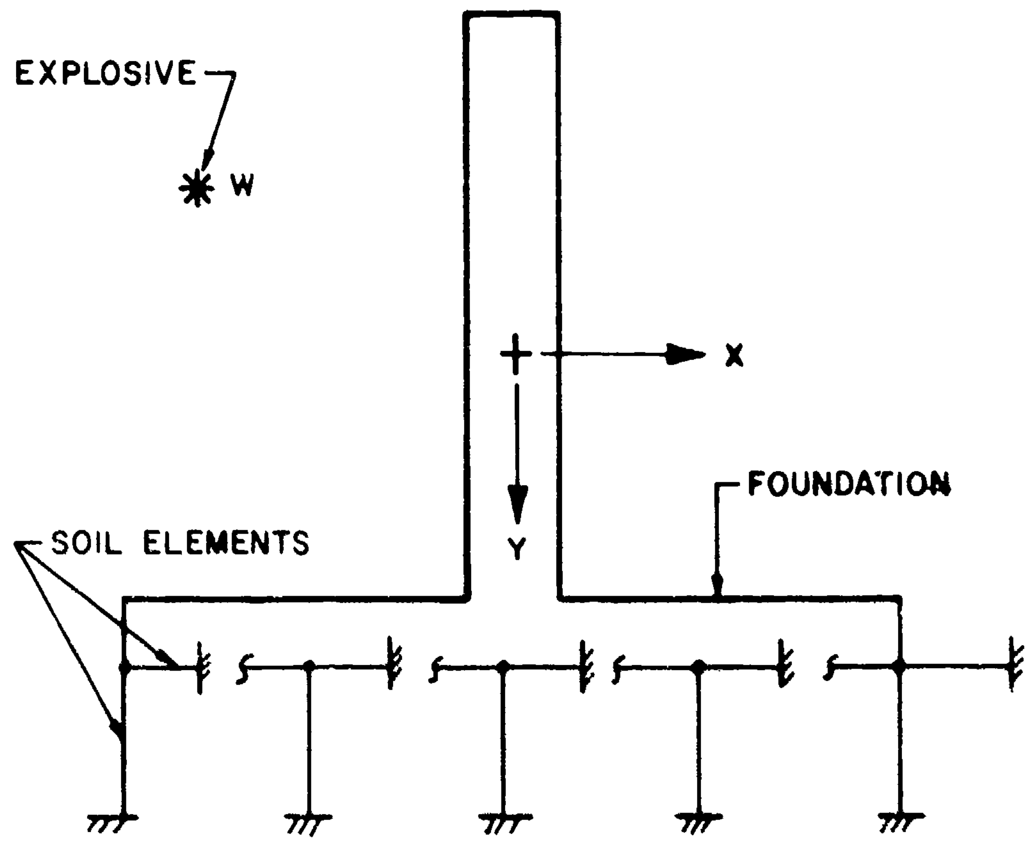


Figure 6. Soil structure interaction.

Resistance to the downward motion of the foundation is developed in the soil by the elastic deformation of the grains and the inter-granular friction generated as the grains slip past each other and fill the voids. Resistance to horizontal translation of the foundation results from the elastic deformations of the grains until the structure begins to slide, after which the motion is resisted by dynamic friction. A more detailed discussion of friction and sliding of the foundation is presented in a subsequent paragraph.

Conventional analysis methods utilize equivalent springs to simulate the soil resistance. Applications of this method are presented in References 3 and 4. Equations for determining equivalent spring constants for the soil are presented by Whitman in Reference 5. These equations were derived utilizing elastic half space theory. The equations for the vertical and horizontal spring constants are:

$$\text{Vertical:} \quad K_y = G\beta_z\sqrt{BL}/(1 - \mu) \tag{4.1}$$

$$\text{Horizontal:} \quad K_x = 2(1 + \mu)G\beta_x\sqrt{BL} \tag{4.2}$$

wherein:

K_y, K_x = total spring constant for vertical and horizontal translation

G = shear modulus for soil

μ = Poisson's ratio for soil

B = length of foundation, along axis of rotation for rocking or normal to direction of horizontal force

L = length of rectangular foundation in plan of rotation for rocking or in direction of horizontal force

β_x = influence coefficient for horizontal spring constant

β_z = influence coefficient for vertical spring constant

Using the spring constants given by Equation 4.1 and 4.2, the elastic constants of the individual soil elements are determined by:

$$k_y = K_y/NS \qquad (4.3)$$

$$k_x = K_x/NS \qquad (4.4)$$

wherein

NS = number of soil elements used in analysis.

The elastic resisting forces are:

$$R_h = \sum_{i=1}^{NS} k_x(u - h'\sin\theta) \qquad (4.5)$$

$$R_v = \sum_{i=1}^{NS} k_y(v + x_i\sin\theta)$$

$$+ \sum_{i=1}^{NS} k_y(V_i)_{ST} \qquad (4.6)$$

$$R = \sum_{i=1}^{NS} k_y(v + x_i\sin\theta)(x_i\cos\theta - h'\sin\theta)$$

$$- \sum_{i=1}^{NS} k_x(u - h'\sin\theta)(h'\cos\theta + x_i\sin\theta) \qquad (4.7)$$

The variables in these expressions are defined below and illustrated in Figure 6.

u, v, θ = translation of structure in the x and y axes and the rotation about the z axis

h' = vertical distance from center of gravity to soil-structure interface

x_i = horizontal distance from center of gravity to soil element attachment point on foundation

$(V_i)_{ST}$ = static deflection under weight of structure at soil element attachment point

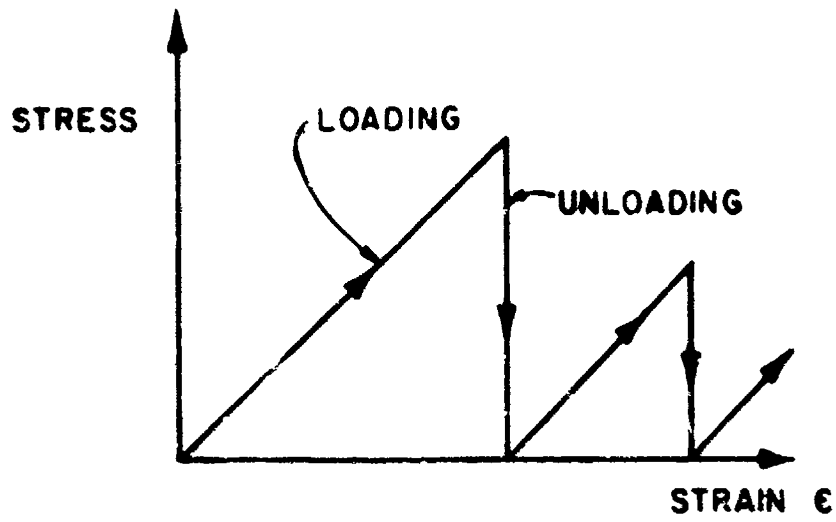
$(u - h'\sin\theta)$ = horizontal displacement of the foundation

$(v + x_i\sin\theta)$ = vertical displacement of soil element attachment point.

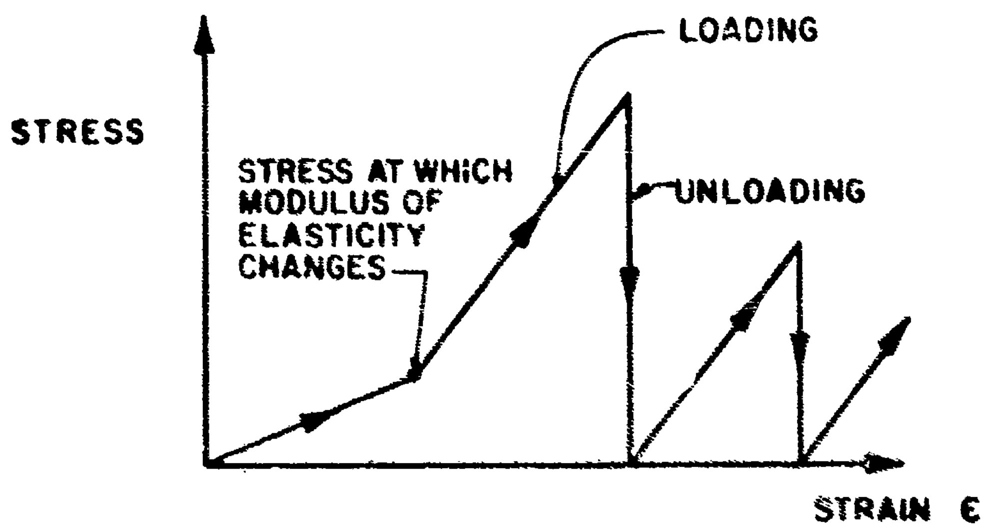
The relationships presented in the preceding paragraph apply when the soil is being loaded. When the foundation moves upward away from the soil, only the energy expended in elastically deforming the grains is recovered. The energy recovered is a small portion of the total energy expended in compressing the soil, with the result that, in effect, the soil rebound is cut off. This lack of rebound is exhibited in both granular and clay soils. Clay soils exhibit more elastic behavior but the major portion of the deformation is still due to slip between the particles. The non-rebounding behavior of the soil is simulated analytically by simply disconnecting the soil element when the attachment point on the foundation attains its peak downward displacement.

The preceding two paragraphs have presented a discussion of the loading and unloading features of the interaction model. In summary, the model behaves elastically when loaded and exhibits no rebound when unloaded. Figure 9 depicts this behavior. The upper portion of the figure shows the loading cycle to be linear. In the lower portion of the figure, a bilinear loading cycle is depicted. This latter curve is a more accurate representation of the actual behavior of the soil. As the loading increases, the voids are filled and a greater portion of the resistance results from the elastic deformation of the grains thereby increasing the stiffness of the soil. Generally, the linear model is adequate for the solution at hand, but when the appropriate data is available, the bilinear model should be utilized in the dynamic analysis.

As noted previously, the resistance to the horizontal motion of the foundation is developed by the elastic deformation of the grains until sliding commences. This resistance can be simulated using a linear function. At some point, the resistance exceeds the friction force on the foundation and sliding commences and continues until the foundation attains its peak horizontal displacement. At this point, the foundation regains contact with the soil and proceeds to displace in the opposite direction. During this stage, as in the initial stage of the motion, the resistance



LINEAR ELASTIC MODEL



BI - LINEAR MODEL

Figure 9. Loading/Unloading cycles for soil structure interaction model.

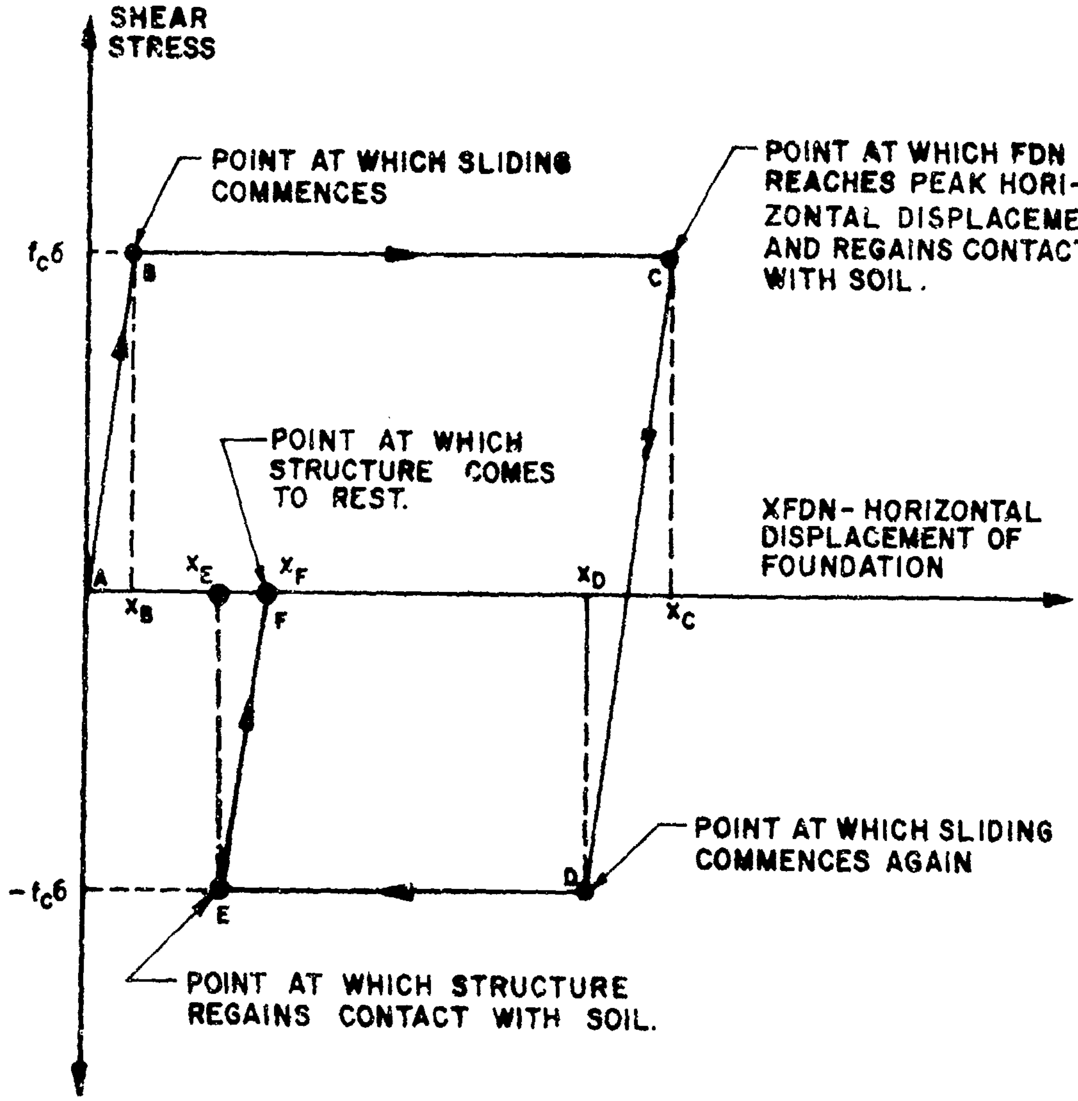


Figure 10. Horizontal resistance vs. deflection.

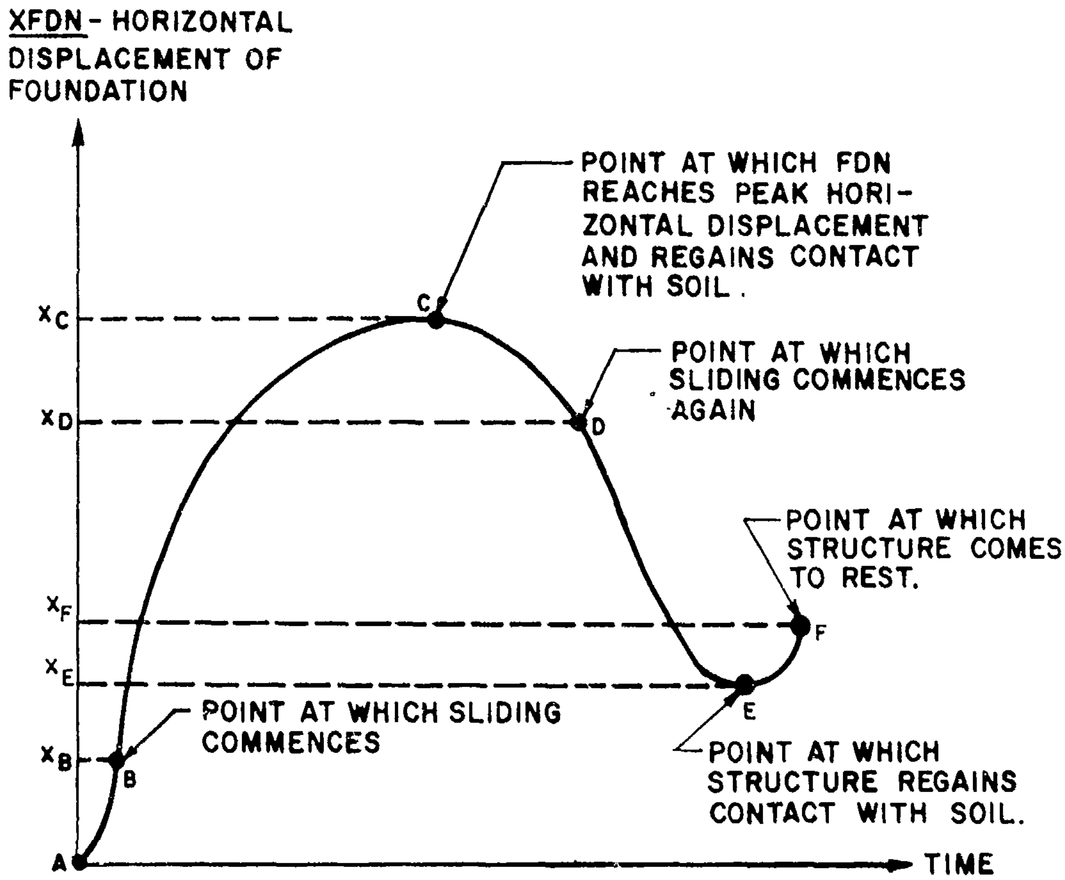


Figure 11. Horizontal displacement history.

is developed by elastically deforming the grains. This effect is illustrated in Figure 10 for a constant normal force. From Point A to Point B, the resistance is linear until the friction force is exceeded at Point B. Sliding commences at Point B and continues until the foundation reaches its peak horizontal displacement at Point C, at which time the structure regains contact with the soil. From Point C to Point D, the resistance is again linear. After Point D, sliding in the opposite direction occurs between the slab and soil. After Point E, elastic soil forces are redeveloped until the structure comes to rest at Point F where a permanent displacement will be realized. Figure 11 depicts the time history of the horizontal motion of the foundation and identifies the key points when the effect of friction enters into the horizontal resistance.

4.3 Soil Properties

Definitive determination of representative values for critical soil properties for use in a design study is highly problematic. Ideally, soil samples should be collected at the construction site and tested under conditions representative of the anticipated operating movement. Soil spring constants would then be evaluated from the test results taking into account:

1. The effect of partial embedment of the footing.

2. The dependence of the spring constants upon the initial static stress as well as upon the magnitude of the dynamic stress increment.

3. The distribution of stresses over the contact area between the foundation and the soil, and

4. The dependence of the spring constants upon the size of the contact area which, in turn, depends upon the variation of the soil molecules with depth or with the presence of a layered soil structure.

Under more realistic circumstances, it is likely that the soil data available to the designer are the result of a minimum of shallow test borings with visual descriptions of the soils encountered accompanying values of "N" as determined from standard penetration tests (N is the number of blows of a 140-pound hammer dropping 30 inches required to drive a sampler of 2-inch outer diameter 1 foot into the soil). It is necessary to correlate this type of information with the modulus of elasticity required for analysis.

Tables 1 and 2 summarize a correlation of modulus of elasticity with soil type and "N" value. The tabulated moduli were extracted from Reference 6. The values presented were derived from repeated load tests and modified utilizing observed resonant frequencies in the material. These values are approximate and should only be used where the time or resources for the determination of the soil parameters by a more rigorous method are not available.

With the data correlation of Tables 1 and 2, the designer, at best, has only a gross estimate of the actual soil properties. The soil properties, especially the modulus of elasticity, affect both the stability of the structure and the strength requirements of the foundation. A gross overestimate of the soil modulus could result in a structure that overturns or experiences large horizontal motions under the action of the blast while a gross underestimate of the soil modulus could result in a failure of the foundation. Consequently, in the absence of more reliable data (such as described in the initial paragraph of this section), the structure should be designed for the range of soil properties (specified in Tables 1 and 2) for the particular type of soil at the construction site.

TABLE 1 SOIL PROPERTIES - NON-COHESIVE SOILS

Soil Classification	Description	"N"	Modulus of Elasticity (psi)	Poisson's Ratio μ*	Friction Factor f_c
Granular	Silts Loose	4	1,000	0.40	0.4
	Very Compact	30	2,000	0.30	0.8
	Sand Loose	10	1,800	0.30	0.5
	Very Compact	50	7,000	0.25	0.7
	Gravel Loose	15	3,000	0.20	0.6
	Very Compact	70	20,000	0.15	0.7
Bedrock			20,000-50,000	0.10	0.7

*For soils below the water table μ = 0.50

TABLE 2 SOIL PROPERTIES - COHESIVE SOILS

Description	Plasticity Index	Condition	"N"	Modulus of Elasticity (psi)	Poisson's Ratio μ*	Adhesion (psf)
Slightly Plastic	1-10	Medium Soft	5	2,000	0.45	500
		Hard	20	5,000	0.45	1,000
Plastic	10-20	Medium Soft	4	2,000	0.45	500
		Hard	15	6,000	0.45	1,000
Very Plastic	20+	Medium Soft	3	2,000	0.45	500
		Hard	12	6,000	0.45	1,000

*For soils below the water table μ = 0.50

SECTION 5

COMPUTER PROGRAM

5.1 Introduction

This section presents the computer program used to implement the procedures (for performing dynamic analyses of protective structures) developed in Sections 3, 4 and 5 of this report.

The program is essentially a special purpose program, designed specifically for performing dynamic analyses of structures subjected to close-in explosions. To this end, the bulk of the input data required for the dynamic analysis is computed internally by the program. Items such as the inertial properties of the structure (weight, moment of inertia, etc.), the time history of the blast loads acting on the structure and the elastic constants and spacing of the soil elements beneath the foundation are computed by the program. These computations are performed for the most common types of cantilever wall and multi-wall barriers such as those shown in Figure 12.

The inclusion of these computations in the program greatly diminishes the quantity of input data entered on punched cards. In addition, the program input is tailored to facilitate the data preparation for the most common types of protective barriers such as those shown in Figure 12. The range of applicability of the program can be extended, however, by overriding the built-in computational routines. In this way, the program can be used to analyze structures of any configuration.

5.2 Program Capabilities

The computer program performs a rigid body analysis of a protective structure subjected to the blast pressures of an explosive detonation. The results of the computerized analysis consist of the displacement, velocity and acceleration time histories of the structure. The bearing pressures beneath the foundation are also determined. Options are included for the computation of the shears and moments for the foundation slab design of cantilever wall barriers and the peak response time for the back wall element (see Figure 14) designed to the incipient failure or post-failure fragment conditions.

The computer program contains three optional modes of operation. They are:

1. Normal Option: The "Normal Option" mode is used for analyzing the most common types of protective structures encountered in explosive manufacturing and storage facilities. It contains internal routines which calculate the inertial properties of the structure and the time history of the blast loads acting on the structure. To compute the load history, the explosive data for TNT were incorporated into the program. The data may be utilized for other explosives by applying a TNT equivalence for the particular explosive to the charge weight used.

2. Special Loading Option: The "Special Loading Option" is used to accommodate rectangular or trapezoidal load histories in the analysis.

3. General Structure Option: The "General Structure Option" is used to extend the applicability of the computer program to structures of any arbitrary configuration.

5.3 Input Requirements

5.3.1 General Input

The input to the program consists of punched cards which contain the following data:

1. The configuration and dimensions of the structure.

2. The properties of the soil for use in the interaction model described in Section 4.

3. The quantities, locations and blast outputs (average impulses on the elements of the structure) of the explosives.

Since the computer program has been designed specifically for the most common types of protective structures, the quantity of the input containing the configuration and the dimensions of the structure and the blast output of the explosives has been greatly diminished. Computational flexibility is retained, however, by including provisions for overriding those features of the program that apply to standard configurations of protective structures. In this way, data applicable to any type of structure can be entered. However, the quantity of data required for this purpose is much greater than what is required for normal program applications.

As noted previously, a computational routine has been installed in the program for the purpose of calculating the peak response time of the back wall element. To utilize this routine, additional input describing the structural details of the element is required. Utilization of this routine as well as the input required for it is optional.

A description of the various input quantities required is contained in the following section.

5.3.2 Configuration of the Structure

As applied to the most common types of protective structures, the structural configuration is described in terms of the number and size of the blast-resistant elements making up the structure. The input required for the "Normal Option" mode of the program is designed specifically for the protective structure configurations shown in Figure 12. Included in the figure are the dimensions and parameters necessary to completely define the structural geometry. The program uses the dimensions illustrated in Figure 12 to compute the following quantities for use in the dynamic analysis of the structure:

1. Weight and moment of inertia of the structure. The computation is restricted to structures constructed of normal weight concrete weighing 150 pounds per cubic foot.

2. Location of the center of gravity of the structure as shown in Figure 14.

3. The areas of the surfaces on the structure subjected to blast pressures. The computation is limited to surfaces normal to the plane of motion of the structure.

4. The location of the centroids of the loaded surfaces relative to the center of gravity of the structure. Only the centroids of the surfaces normal to the plane of motion of the structure are computed.

5. The plan area of the foundation.

In applications of the program to non-standard configurations, the quantities listed above, with the exception of Item 5, have to be computed beforehand and entered using the optional input formats provided for this purpose. This optional form of

entering the data is the "General Structure Option". The pertinent data relating to the dimensions of the foundation is still required and must be entered using the regular input card for the structural geometry.

5.3.3 Properties of the Soil

The soil properties are utilized with the soil structure interaction model described in Section 4. The quantities required are the modulus of elasticity, Poisson's ratio and the appropriate friction constant for the soil. Soil properties for various soils are provided in Section 4.3. Shape factors for the foundation (as defined in Reference 5) are also required. This data is utilized by the program to compute the elastic spring constants for the loading cycle of the interaction model.

The inclusion of non-linear behavior is accomplished by entering two different moduli of elasticity and the normal stress at which the modulus changes. For bilinear soil behavior, the interaction model utilizes a bilinear loading cycle in the analysis with spring constants being computed for both moduli of elasticity.

5.3.4 Blast Output of Explosives

In applications of the program to standard structural configurations, the blast output of the explosives is described in terms of charge weights and locations and the average unit impulses on all loaded surfaces. This limited description of the explosive blast output is all that is required when utilizing the "Normal Option" mode of the program. The program uses this data to compute the load history on the structure. The computation proceeds in two stages.

In the first stage, the following quantities are computed utilizing the procedure presented in Section 3.3, the weights and locations of the explosive charges entered on the input cards, and the TNT explosives data contained in the program:

1. The smallest load duration on any surface.

2. The arrival time of the blast wave on every surface.

3. The arrival time of the blast plus the average duration of the loading on every surface.

The above quantities are computed for each explosive charge and stored internally in the computer.

In the second stage, the total blast load history on the structure is computed. The loadings on the structure produced by each explosive charge are computed individually. In the computation cycle for each explosive charge, the load on each surface is computed in the following manner. First, the program utilizes the impulse data entered on the input cards and the quantities (Items 2 and 3) listed on the preceding page to determine the peak pressure acting on the surface. The pressure is computed using a triangular (linear) pressure-time history. The peak load on the surface is then computed by multiplying the peak pressure by the area of the surface. After this, the load history is determined by dividing the triangular load-time function into a series of small equal time increments. In order to insure that the total impulse is considered in the analysis, the program digitizes the load history at a time increment equal to 1/20 of the shortest load duration on any one surface of the structure. As the load-time history is digitized, the time history of the moment of the load around the center of gravity of the structure is also computed. The load- and moment-time histories are then added to the total force vector for the structure.

Application of the program to non-standard protective structures requires that the data listed on the preceding page (Items 1, 2 and 3) be computed and entered on the alternate input formats provided. This alternate form of entering the data is the "Special Loading Option" which can also be utilized to accommodate rectangular and trapezoidal pressure-time functions in the analysis.

5.3.5 Structural Details of the Back Wall Element

This input consisting of structural design data relating to laced reinforced concrete walls is entered for the purpose of computing the maximum response time of the back wall element. In this report, the back wall element is defined as the principal blast-resistant wall perpendicular to the x-y plane of motion of the structure as shown in Figure 14. The response time computation is performed using the procedures outlined in Chapters 5 and 6 of Manual TM 5-1300.

Generally, the response time is of interest to the user in judging the adequacy of the rigid body approximation for computing the gross response of the structure. A small element response time in comparison to the gross response time of the structure indicates that the rigid body approach is adequate to the task. In cases where the response times of individual elements are nearly equal to that of the gross structural motion, the rigid body method will yield conservative results. This is

especially true when the overall structure responds well before the back wall element responds. For these cases which are not common, a more sophisticated approach would be required.

The computation is performed for elements designed to incipient failure or to the post-failure fragment conditions. In the event of the latter, the response time of the element is used as an upper time limit on the rigid body response as no further computations are required after the wall has failed.

5.4 Computer Usage and Restrictions

The program is written in FORTRAN IV for the CDC 6600 computer. The FORTRAN coding for the program can be found in Appendix D.

The size restrictions imposed by the dimensional constraints of the program are summarized below:

Item	Maximum Number
Number of charges	20
Number of wall elements	4
Number of soil elements	15
Number of force-time stations	1,000
Number of output-time stations	1,000
Number of loaded surfaces	5

The results of the analysis are stored internally in the computer until the numerical integration is completed after which they are retrieved and printed out. There is no limitation on the number of integration time steps that can be utilized in the analysis. However, there is a limitation on the amount of data that can be stored internally in the computer. This limitation, established by the dimensional constraints of the program, determines the maximum number of output time stations allowed. Therefore, caution must be exercised in specifying the number of integration time steps to be skipped between output time stations. If an insufficient number of integration time steps are skipped between output time stations, the quantity of data stored in the computer will exceed the dimensional limitations of the program. This will result in premature termination of the calculation.

5.5 User's Manual

5.5.1 Introduction

The input to the computer program is presented in coded card format in Sections 5.5.2 and 5.5.3.

Section 5.5.2 contains the input data forms required for the "Normal Option" of the program. The "Normal Option" mode of the program is applicable only to the structural configurations shown in Figure 12. The program, in this mode, considers only the triangular (linear) pressure-time function in computing the load history.

Section 5.5.3 contains the additional data forms required for the "General Structure" and "Special Loading Options". Section 5.5.4 describes the input terminator cards. The composition of the data decks for the various options available in the program is presented in Section 5.5.5. Following this is Section 5.5.6 which contains user instructions for running several computer analyses consecutively (Multiple Job Processing).

5.5.2 Input Data Forms: Normal Option

There are 6 types of cards used to specify data for the "Normal Option" mode of the program. Each type of card is described below in terms of data format, definition and field allocations. The numbers above the graphic representation of each card identify the last column in each field of the card. In fields designated "I", the quantity must be right adjusted to the last column in the field. No decimal point is required for "I" formatted input. In fields designated "F", a decimal point is required; however, the number can be located anywhere within the field. A plus sign for a positive quantity is not required and will abort the execution of the program. Minus signs for negative quantities must be placed in the first blank column to the left of the number. The cards are numbered (Card Type 1, 2, etc.) according to the order in which they are read in by the program.

Card Type 1 - Structure Description Card (Required)

This card may contain alphanumeric information in Columns 2-71 that will be printed at the top of each page of the output.

Card Type 2 - Problem Specification Card (Required)

5	10	15	20	25	30	35	40	45	50	55	60	65	
NP	N	NS	NUMTM		ICI	ICAI	NDEL2	NUMPT	NWALL	NVEL	NFDN	NLOAD	

("I" FORMAT - ALL FIELDS)

NP = number of charges

N = number of walls

NS = number of soil elements

NUMTM = number of integration time steps

IC1 = 0 output limited to a tabulation of maximum displacements, soil pressure and foundation shear and moment

= 1 program prints displacements, soil resistance forces and soil bearing pressures at every output time station

ICA1 = 0 Normal Option: mass of the structure, location of the center of gravity, areas of loaded surfaces and the location of their centroids relative to the center of gravity are calculated from structure geometry entered on Card Type 4. Pressure-time histories are calculated using structure geometry input on Card Type 4 and charge data input on Card Type 5.

= 1 General Structure Option: Internal computation of aforementioned data is bypassed and the information entered using Card Types 6 and 8 through 12.

NDEL2 = constant used for changing integration time step; normally, the time step used in the computation is 1/20 of the smallest load duration on any one surface of the structure. If this option is exercised, the time step will be multiplied by this factor. The integration time step is altered only after the pressure on the structure has decayed to zero.

NUMPT = number of integration time steps skipped between output time stations. NOTE: NUMTM/NUMPT $\leq$ 1000.

NWALL = 1 the program calculates the maximum response time of back wall element for incipient failure or post-failure fragments.

NVEL = 1 the acceleration and velocity of the structure is printed at every output time station.

NFDN = 1 the maximum moment on the foundation at the wall face and the maximum shear and corresponding moment at a specified distance from the wall face are computed by the program. The specified distance used in the computation is 15 percent of the length of the foundation overhang. The width of a wall haunch is included in the computation, if one is present. This option applies only to cantilever wall type barriers.

NLOAD = 0 Normal Option: loading on the structure will be calculated internally using the structure geometry entered on Card Type 4 and the charge data entered on Card Type 5.

NLOAD > 0 Special Loading Option: internal computation of the loading will be bypassed and the loading data will be entered on Card Types 6 and 12. The value of "NLOAD" is used as the number of loaded surfaces on the structure. When this option is not used in conjunction with the "General Structure Option", enter zero for the parameter "ICA1".

Card Type 3 - Soil Properties Card (Required)

10	20	30	40	50	60	70	
E1	E2	SMTP	f_c	μ	βx	βz	

("F" FORMAT - ALL FIELDS)

E1 = modulus of elasticity (psi) of first portion of bilinear stress-strain curve

Card Type 3 (continued)

E2 = modulus of elasticity (psi) of second portion of bilinear stress-strain curve. For linear stress-strain curves, enter for "E2" the value of "E1".

SMTP = stress (psi) at which modulus of elasticity changes (see Figure 9, page 22). For linear stress-strain curves, enter a value of 10000.0 for SMTP.

f_c = coefficient of friction between soil and base of structure for non-cohesive soils or adhesion constant (psf) for cohesive soils

μ = Poisson's ratio for soil

β = influence coefficient for calculating soil spring constants:

β_x is the coefficient for the horizontal spring constant

β_z is the coefficient for the vertical spring constant

Card Type 4 - Structure Geometry Card (Required) (See Figure 12)

10	20	30	40	50	60	70	
TW	C9	L	HW	SSB	HB	HAUNH	

("F" FORMAT - ALL FIELDS)

TW = back wall thickness (in)

C9 = ratio of foundation thickness to back wall thickness (TS/TW)

L = length of back wall (ft)

HW = height of back wall (ft)

SSB = ratio of length of loaded area of foundation to total length of foundation (L_F/B)

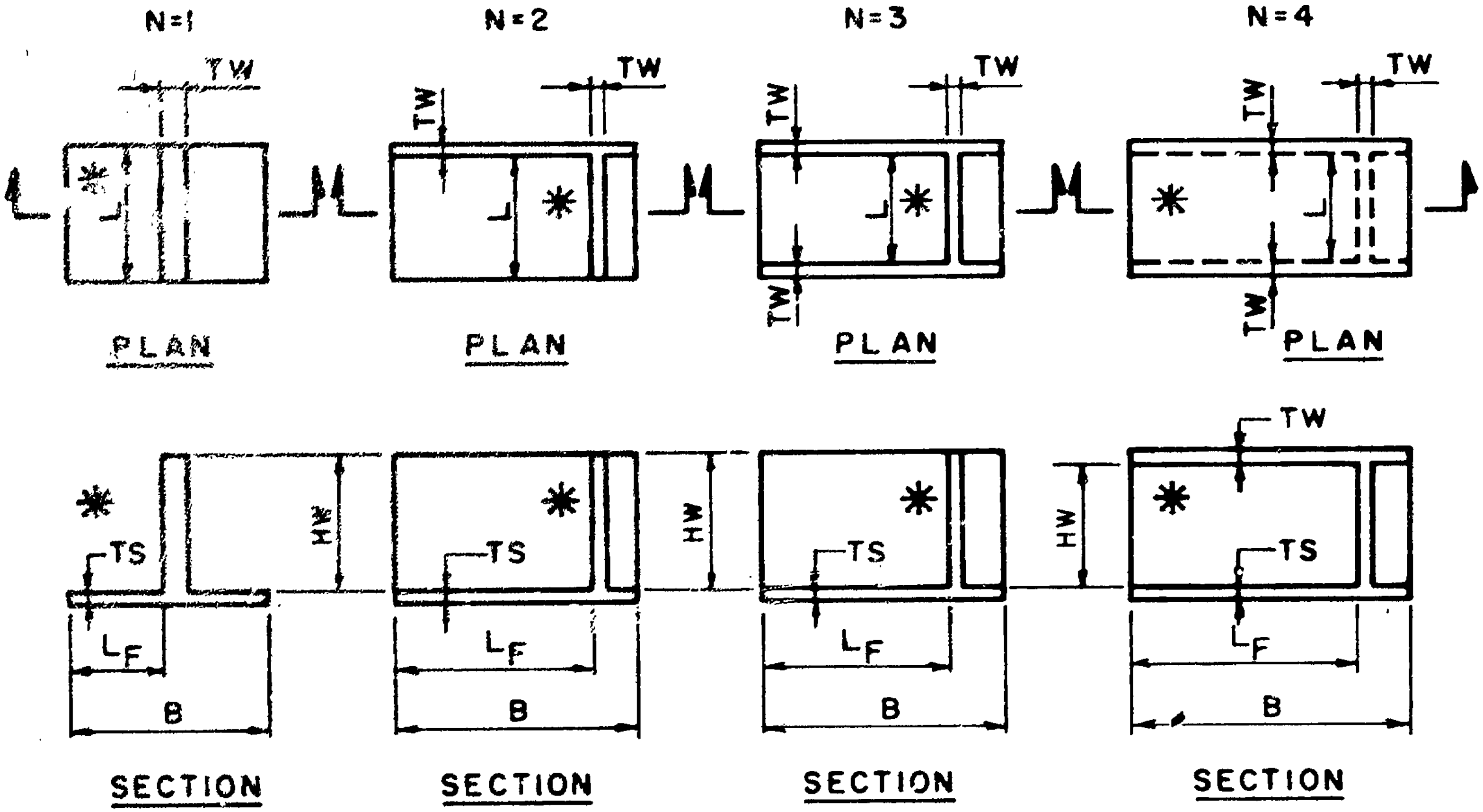


Figure 12. Structure geometry parameters.

HB = ratio of height of back wall to length of foundation (HW/B)

HAUNH = width of back wall haunch (in)

<u>Card Type 5</u> - Charge Data Cards (Required for Normal Option only) (See Figure 13)

<u>Normal Option</u>: computation of pressure-time histories is performed internally by the program utilizing the data on these cards and the TNT explosive data contained in the program

10	20	30	40	50	60	70	
R_A	W	$i_b(1)$	$i_b(2)$	$i_b(3)$	l	h	

("F" FORMAT - ALL FIELDS)

R_A = distance from center of charge to rear face of back wall (ft)

W = charge weight (lbs)

$i_b(1)$ = unit blast impulse on back wall (psi-ms)

$i_b(2)$ = unit blast impulse on foundation (psi-ms)

$i_b(3)$ = unit blast impulse on roof (psi-ms)

l = minimum distance from charge to an adjacent wall (ft)

h = height of charge above foundation (ft)

<u>NOTE</u>: One "Charge Data Card" is required for each explosive charge.

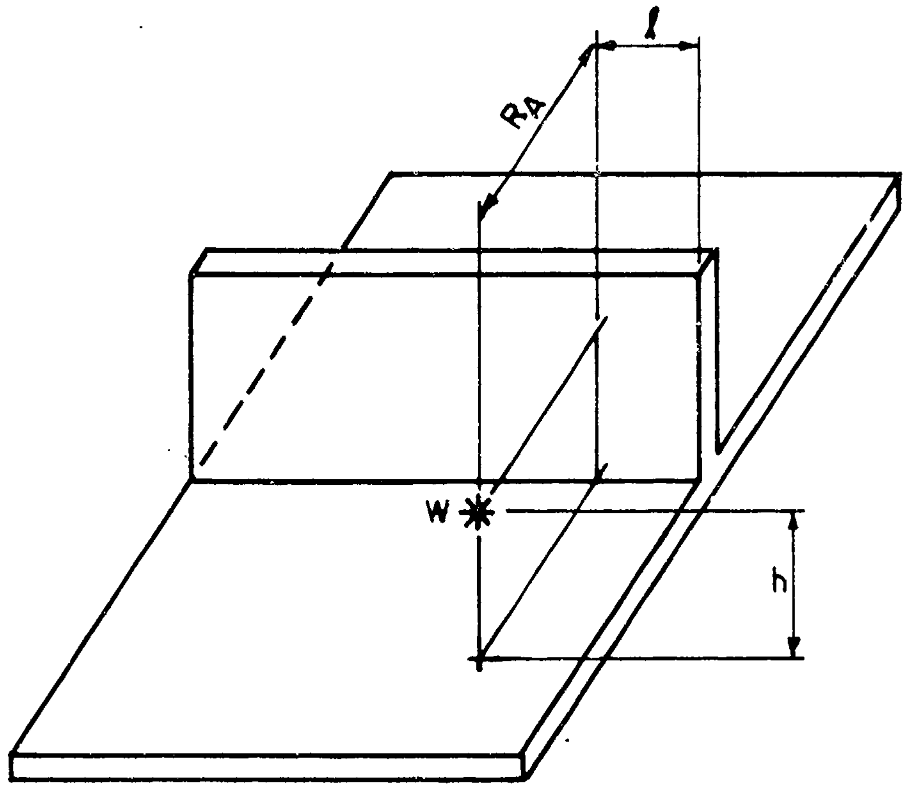


Figure 13. Charge data parameters.

Card Type 7 - Back Wall Structural Details Card (Optional; may be used with Normal and Special Loading Options)

This option is used if the maximum response time of the back wall element is required. The peak response time is calculated for the incipient failure or the post-failure fragment conditions. In the event of the post-failure fragment condition, this quantity is used as an upper time limit on the response of the structure. The dimensions and parameters entered on this card are defined and illustrated in Chapter 5 of Reference 1.

10	20	30	40	45	50	60	70	80
Σi_b	d_c	p_V	p_H	x	y	f_{ds}	$(KLM)_u$	v_f

("F" FORMAT - ALL FIELDS)

Σi_b = summation of unit blast impulses on back wall element (psi-ms)

d_c = distance between the centroids of the tension and compression reinforcement (in)

p_V = reinforcement ratio vertical

p_H = reinforcement ratio horizontal

x or y = yield line location (in)

f_{ds} = dynamic steel design stress (psi)

$(KLM)_u$ = plastic load mass factor

v_f = velocity of post-failure fragments (in/ms). This quantity is required for elements designed to the post-failure fragment condition only.

NOTE:

1. If the structure being analyzed is a cantilever wall, enter only Σi_b, d_c, p_V, f_{ds}.

2. To use this option, a value of 1 must be entered for the parameter "NWALL" on Card Type 2.

5.5.3 Input Data Forms: General Structure and Special Loading Options

There are 6 additional types of cards (Card Types 6 and 8 through 12) that are required for the "General Structure Option" and two additional types of cards (Card Types 6 and 12) that are required for the "Special Loading Option". These cards are required in addition to Card Types 1 through 4. Each type of card is described on the following pages in the manner specified in Section 5.5.2. Card Types 6 and 12 are utilized in lieu of Card Type 5 ("Charge Data Card") to enter the loading data. Card Types 8 through 11 are used to enter the inertial properties and the geometry of the structure. The data on Card Types 6 and 9 through 12 is used by the program to compute the load history on the structure.

Card Type 6 is used to enter the arrival time of the blast wave on the structure and the smallest duration of the loading produced by any one explosive charge on any surface.

Card Type 8 is used to enter the inertial properties of the structure and the location of the center of gravity of the structure. The dimensions required to locate the center of gravity are shown in Figure 14.

Card Types 9 through 11 contain geometry data pertaining to the loaded surfaces of the structure. As discussed in Section 2, the analysis treats the structure as a rigid body, constrained to move in one plane; therefore, only loading and geometry data pertaining to surfaces normal to the plane of motion of the structure have to be included in the input data deck.

Card Type 9 is used to enter the areas of those surfaces directly exposed to the blast pressures.

Card Type 10 is used to enter the location of the centroid of a loaded surface relative to the center of gravity of the structure.

Card Type 11 is used to enter the horizontal and vertical components of a unit vector normal to a loaded surface. The vector defined on this card must be directed towards the surface.

Areas for all loaded surfaces can be entered on Card Type 9 whereas one each of Card Types 10 and 11 is required for each loaded surface. Card Types 10 and 11 are entered in two separate groups, that is, one group contains all Card Types 10 and the other contains all Card Types 11.

Card Type 12 contains loading data that includes the average impulse on the surface, the arrival time of the blast wave on the surface and the sum of the arrival time of the blast wave plus the load duration on the surface. The surface loading data is entered in groups. Each group contains the surface loadings produced by one explosive charge. In each group, one "Surface Loading Data Card" (Card Type 12) is entered for loaded surface.

Figure 16 on page 51 illustrates the input data deck for the "Special Loading Option". The figure shows several groups of data cards, each labeled with a charge number and the encircled number 12. Each group contains several cards, with each card containing the loading data (average impulse, arrival time and load duration) for one loaded surface. For the "Special Loading Option", the surface loading data cards must be ordered (within each group) as follows:

Order of Data Card Within Group	Surface
First Card	Back Wall
Second Card	Floor or Foundation
Third Card	Roof (if present)

If the data cards are not in the correct sequence, the results of the analysis will be erroneous.

Figure 17 on page 52 illustrates the input data deck for the "General Structure Option". The figure shows several groups of data cards (one group each for Card Types 9, 10 and 11 with the card numbers encircled) in addition to the groups containing the loading data cards (Card Type 12). Although the groups must be entered in the same order as shown in the figure, within each group a fixed order for entering the data for the loaded surfaces is not required. However, the order in which the data is entered must be the same for each group; that is, if the areas entered on Card Type 9 are for the roof, floor and back wall in that order, then the surface data entered in the remaining groups (Card Types 10, 11 and 12) must also be in the same order. Changing the order of the input in each group will cause erroneous analysis results.

Card Type 6 - Time Step Data Card (Required for both options)

10	20	
TASM	TOLG	

("F" FORMAT - ALL FIELDS)

TASM = time of arrival of the blast wave on the structure. This quantity is determined by computing, as described in Section 3.3, the time for the blast wave from any charge to traverse the least distance from that charge to a point on the structure. The smallest quantity computed for any explosive charge is the time of arrival of the blast wave on the structure. This value is used as the first integration time station in the analysis.

TOLG = smallest duration of loading produced by any one explosive charge on any surface of the structure.

Card Type 8 - Mass Data Card (Required for General Structure Option only) (See Figure 14).

10	20	30	40	50	
WT	I	XB	YB	XR	

("F" FORMAT - ALL FIELDS)

WT = weight of structure (lbs)

I = mass moment of inertia (lbs-sec^2/in)

XB = horizontal distance in inches from center of gravity to rear face of back wall element

YB = vertical distance in inches from center of gravity to top of the foundation slab

XR = horizontal distance in inches from center of gravity to the left end of the foundation

NOTE: The signs of the dimensions entered on this card must be consistent with the sign convention of the x-y coordinate system shown in Figure 14.

Card Type 9 - Loaded Surface Area Card (Required for General Structure Option only)

10	20	30	40	50	
AFACE(1)	AFACE(2)	AFACE(3)	AFACE(4)	AFACE(5)	

("F" FORMAT - ALL FIELDS)

AFACE(i) = area of surface in square inches. The area is to be entered for each loaded surface on the structure.

Card Type 10 - Loaded Surface Centroid Card (Required for General Structure Option only)

10	20	
XCORD(I)	YCORD(I)	

("F" FORMAT - ALL FIELDS)

XCORD(i) = horizontal distance in inches from the center of gravity to the centroid of the surface

YCORD(i) = vertical distance in inches from the center of gravity to the centroid of the surface

NOTE:

1. One "Loaded Surface Centroid Card" is required for each loaded surface of the structure.

2. The signs of the dimensions must be consistent with the sign convention of the x-y coordinate system shown in Figure 14.

Card Type 11 - Loaded Surface Normal Vector Card (Required for General Structure Option only)

10	20	
UVECT(1)	UVECT(2)	

("F" FORMAT - ALL FIELDS)

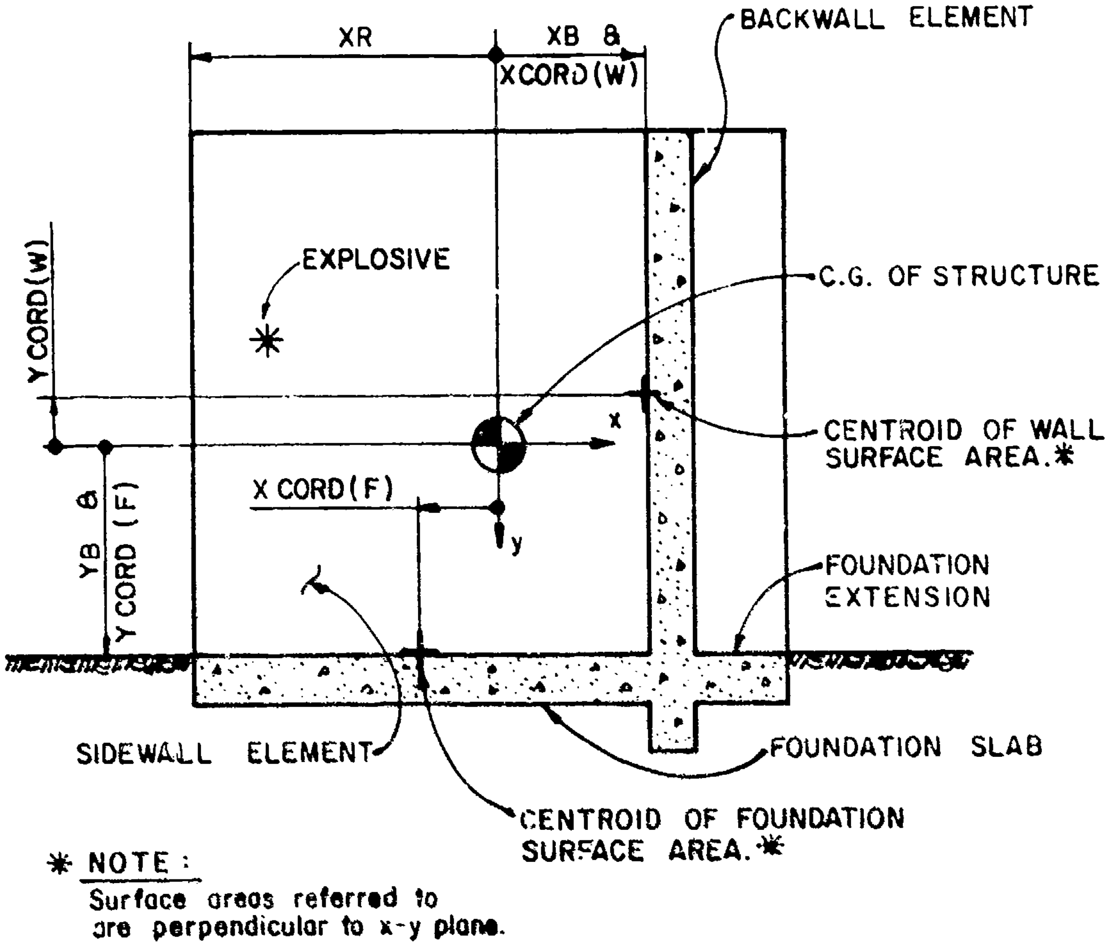


Figure 14. Center of gravity location: Card Type 8.

UVECT(1) = horizontal component of a unit vector normal to the surface

UVECT(2) = vertical component for a unit vector normal to the surface

NOTE:

1. One "Loaded Surface Normal Vector Card" is required for each loaded surface of the structure.

2. The signs of the vector components must be consistent with the sign convention of the x-y coordinate system shown in Figure 14.

Card Type 12 - Surface Loading Data Card (Required for both options)

10	20	30	40	
i_b	t_A	t_{AO}	P2/P1	

("F" FORMAT - ALL FIELDS)

i_b = unit blast impulse on surface (psi-ms)

t_A = arrival time of blast wave on surface (sec)

t_{AO} = arrival time of blast wave plus duration of loading on surface (sec)

P2/P1 = ratio of final pressure to initial pressure on surface

5.5.4 Input Terminator

Following the input data cards are the input terminator cards which signal the program that no further data is to be entered. The program will then execute a normal exit. The input terminator cards are:

1. One (1) blank card

2. One (1) card with a negative integer in Columns 1 - 5.

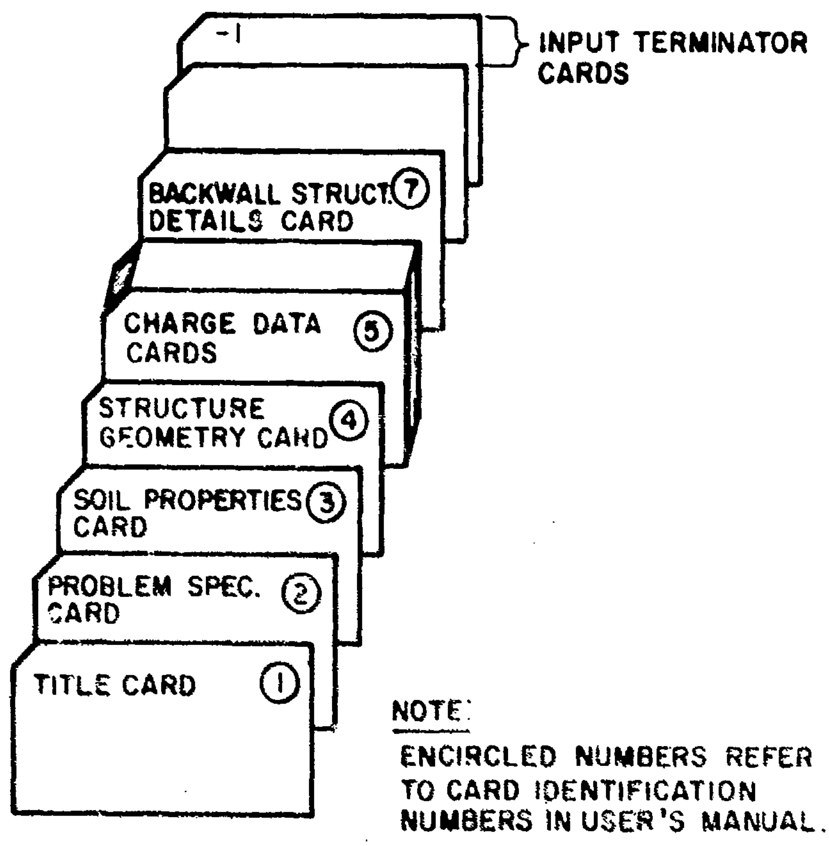


Figure 15 Input data deck: Normal Option.

5.5.5 Input Data Decks

This section presents illustrations of the input data decks for the three options of the computer program. A discussion of the required input is provided below:

1. Normal Option: Standard Configuration and Loading History

   The "Normal Option" requires the least amount of data. The data deck is illustrated in Figure 15. The back wall details data card (Card Type 7) has been included in the deck but it can be omitted if the user so desires.

2. Special Loading Option

   The "Special Loading Option" is used to accommodate rectangular or trapezoidal load histories in the analysis. It is also used in conjunction with the "General Structure Option" to accommodate structures of any arbitrary configuration. This option requires considerably more input data than the "Normal Option".

   The data deck for the "Special Loading Option" is shown in Figure 16. The back wall element response computation can also be included in this option, if so desired.

3. General Structure Option

   The "General Structure Option" is utilized for structures of any arbitrary configuration. It requires the greatest amount of input of all the options available in the program. In addition to the load history data necessary for the "Special Loading Option", all of the data pertaining to the inertial properties and the geometry of the structure are also required. The data deck for the "General Structure Option" is shown in Figure 17.

5.5.6 Multiple Job Processing

Several problems can be processed in one computer run by simply stacking the input data decks for each problem one after the other. The input terminator is then placed after the last data deck.

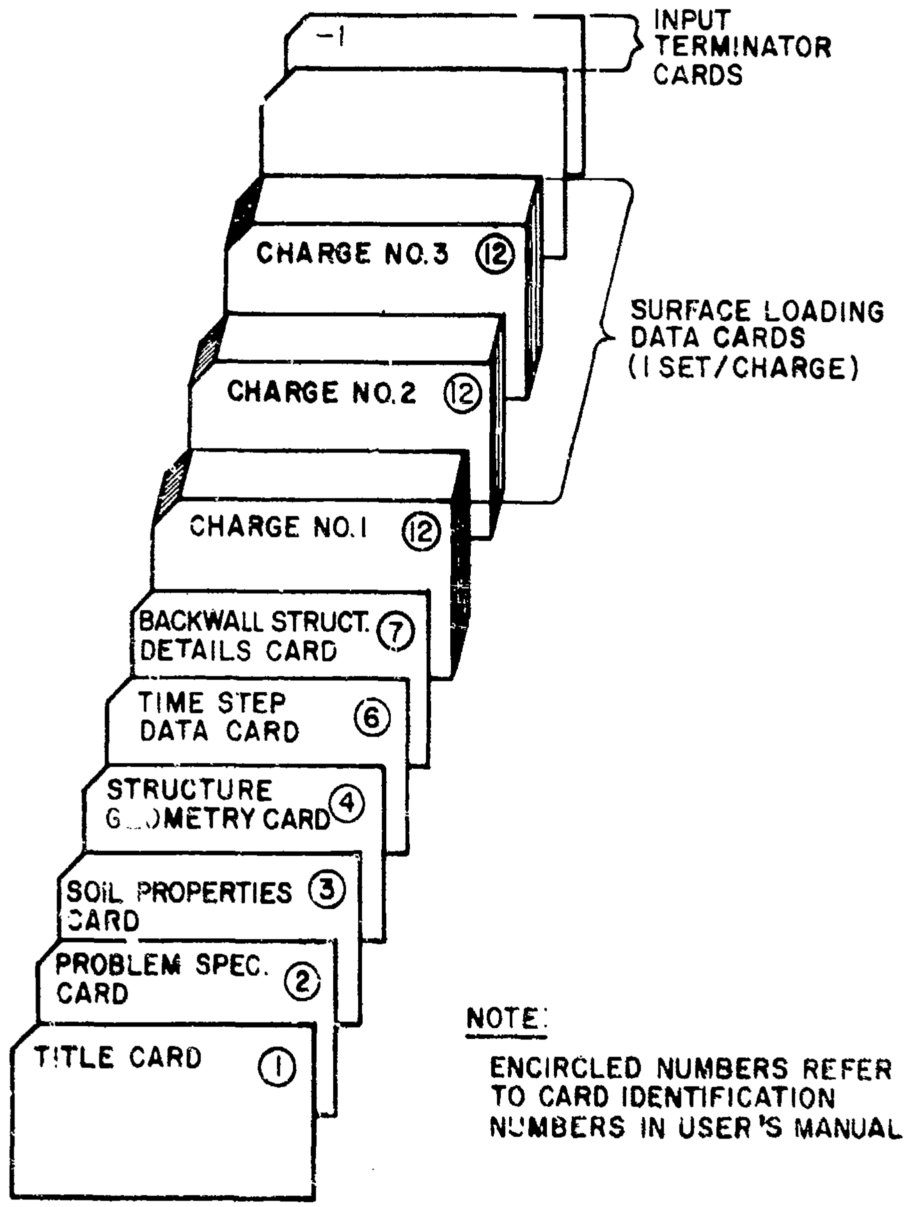


Figure 16. Input data deck: Special Loading Option.

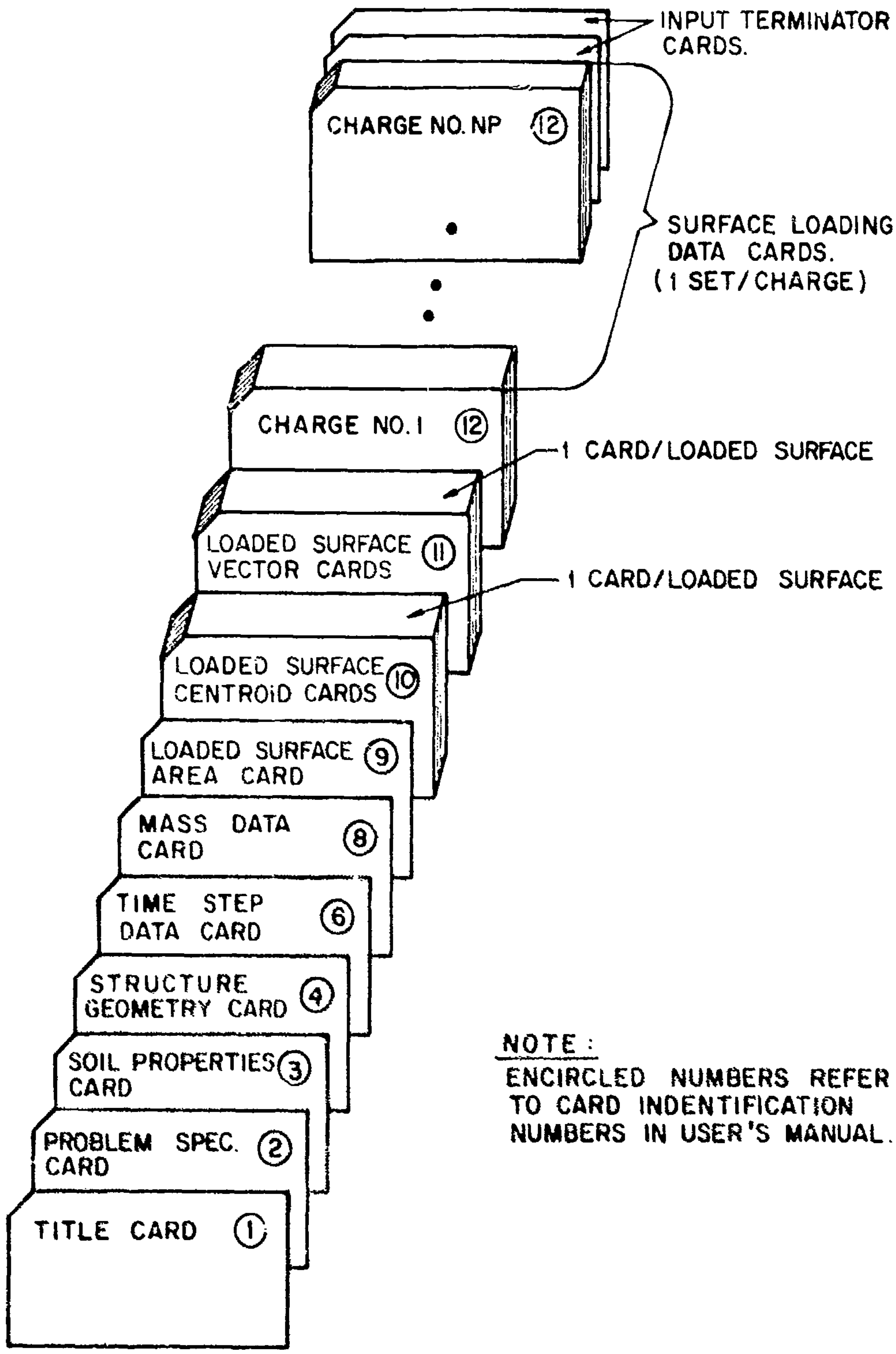


Figure 17. Input data deck: General Structure Option.

SECTION 6

COMPUTER PROGRAM OUTPUT

6.1 Introduction

This section presents a description of the computer program printed output. Included also is a discussion on the utilization of the output with emphasis on that portion related to the design of foundation slabs.

Samples of the printed output are presented in Appendix D.

6.2 Description of Output

6.2.1 Summary of Output

The computer program output consists of three parts: (1) a summary of the input parameters used in the analysis; (2) the loading on the structure; and (3) the response of the structure to the applied loads.

The printing sequence has been designed to provide the input summary as a single block followed by a series of data blocks containing the blast loads on the structure. These data are arranged to present the loads associated with each explosive charge separately. Descriptive data about the charge are printed first. This is followed by the pressures and forces acting on each loaded face of the structure in sequence. The second charge is then described and the loads acting on the loaded faces due to this charge are printed. Finally, the structure's response to the load history is given.

6.2.2 Summary of Input

The input summary includes the program control parameters, the basic dimensions of the structure and the elastic properties of the soil. Both the horizontal and vertical spring constants for the soil are presented. Where the soil behavior is bilinear, both moduli of elasticity are given. In addition, the weight, mass, mass moment of inertia, the significant dimensions (illustrated in Figure 14) locating the structure center of gravity and the integration time step used in the analysis are tabulated. Presentation of the input data in this form facilitates checking and tabulation of the problems.

6.2.3 Blast Loads on Structure

The loads produced by each explosive charge acting on each wall are presented in sequence. Where a multi-charge arrangement occurs, a separate set of load histories is presented for each charge after a description of that charge. The charge descriptive output includes the weight of explosive and its location relative to the back wall, floor and side walls of the structure. This data along with the average impulse acting on each wall is omitted when the "Special Loading Option" is exercised.

The data set for each loaded face includes the average impulse, the surface area, the location of the centroid of the area with respect to the structure center of gravity, the initial and final pressures on the surface and the times at which they occur. Time histories of the load and the moment produced by the load relative to a horizontal axis through the center of gravity are also presented.

Following the above data, a summation of all the horizontal and vertical loads acting on the structure together with the resultant moment with respect to the center of gravity is presented.

6.2.4 Response of the Structure

When the response time option is exercised, the input data associated with the design of the back wall element is printed followed by the peak response time of this wall.

In general, the output contains displacement, velocity and acceleration time histories of the structure resolved into horizontal and vertical components at the center of gravity and an angular component about an axis which passes through the center of gravity and is perpendicular to the plane of motion. Similar data are presented for the foundation. The foundation quantities are found in a column headed "XFDN".

The format of the printout presents several groups of tabulations. The first tabulation includes the displacements of the center of gravity, horizontal displacement of the foundation and the soil "Resisting Forces". These latter are summations of the forces in the horizontal and vertical soil elements and the moments of these forces about the center of gravity of the structure. The second tabulation contains the acceleration- and velocity-time histories of the structure. The horizontal velocity-time history of the foundation is also included under the heading "XFDN".

The third data group consists of the variation, with time, of the bearing pressures in the soil. As discussed previously, the soil is represented in the analysis as a series of discrete elements attached to the foundation at equally spaced intervals. The quantities printed are the bearing pressures at the soil element attachment points. A value of zero for the bearing pressure indicates that the foundation at that point is moving upward away from the soil.

The response-time histories are followed by a tabulation of significant response parameters which include the maximum upward deflection of the toe of the foundation. The toe is that part of the foundation resisting the overturning motions of the structure. If the toe leaves the ground, this deflection will be the maximum upward deflection. If the toe remains below the ground, it will actually be the minimum downward deflection.

If the structure reaches its peak rotation, the tabulation will include the maximum horizontal and vertical displacements of the center of gravity, the overturning angle (rotation of structure at which overturning occurs), the maximum rotation of the structure, and the ratio of the maximum rotation to the overturning angle. The output includes the maximum upward displacement of the center of gravity, the maximum bearing pressure in the soil and the foundation design loads for a cantilever wall type barrier. If the peak response has not been attained, this output will be omitted and a message printed, indicating that more time is required in the analysis. If this occurs, the number of integration time steps must be increased and the analysis performed again until the maximum response is reached.

The volume of output can be limited by either deleting whole sections or increasing the number of integration time steps skipped between printouts.

6.3 Use of Output

6.3.1 General

The output of this computer program may be used for three primary purposes: (1) to evaluate the response of the structure; (2) to detect errors in either the input data or the analysis; and (3) to design foundation slabs.

The first two require no explanation. The third, however, is discussed in the section that follows and treated in detail in Appendix C.

6.3.2 Foundation Design

Design procedures for foundations of protective structures vary according to the configuration of the structure. Basically, all protective structures depend, to some extent, on the soil beneath the foundation, to resist the structure overturning and/or sliding motions. The extent of this dependence on the soil is a function of the configuration and size of the structure, and where applicable, the configuration and size of larger structures to which the protective structure is tied.

Large multi-cell barricades, such as the one shown in Figure 5, will experience gross rotational and sliding motions under the action of the blast. However, the massive blast wall elements and the equally massive foundation, combined with the substantial width of the foundation, will severely limit the gross motions of the structure to the extent that they are no longer a factor to be considered in the design. This is also true for barricades with a single row of cells. Foundations for these structures are designed primarily to develop the blast wall elements. Long foundation extensions, projecting well beyond the extent of the cell, are not required. The length of the foundation extension, if one is required, is usually established by the anchorage required for the reinforcing steel in concrete.

Barrier walls and their foundations that are integral with larger structures (such as explosive manufacturing or storage facilities) experience large rotational motions but are generally not susceptible to overturning. The resistance to overturning is generated by mobilizing the mass of the larger structure through the foundation and other components of the larger structure (such as the foundation walls shown in Figure 4). In these situations, the foundation design is based on developing the blast wall elements. In some cases, depending upon the configuration of the larger structure and the location of the barrier wall within it, some portion of the resistance to the overturning motions may have to be generated in the soil beneath the foundation. Two examples of this condition are: an excessively tall interior barrier wall restrained only by the foundation of the structure and a barrier wall located at the end of a structural floor slab.

In these cases, the foundation is initially designed to develop the blast wall element. Then, in order to determine the peak soil pressures acting on the foundation, an overturning analysis is performed. The analysis considers the barrier wall acting together with some effective segment of the structural foundation. The foundation is then checked to insure that it can resist the moments and shears produced by the peak soil pressures.

Simple cantilever wall barriers and single cell cubicles generally experience relatively large gross motions, under the action of blast loads, which are resisted entirely by the compression forces developed in the soil beneath their foundation extensions (see Figures 1 and 2). They are therefore highly susceptible to overturning. The compression forces in the soil impart shear and bending stresses in the foundation extension for which the foundation slab must be designed. For single cell cubicles, the foundations are designed both to develop the blast wall elements and to resist the compression forces in the soil. On the other hand, the foundation extension for a cantilever wall barrier is designed primarily to resist the soil bearing pressures. This comes about because the response of the cantilever wall barrier on the soil closely approximates a true rigid body response. Consequently, the only significant loadings on the foundation extension are the soil pressures generated as the structure responds to the blast loads.

Designing the foundation of a protective structure to develop the strength of the blast wall elements is a relatively simple task. Basically, the procedure entails designing the foundation slab for the ultimate bending moment capacity of the wall.

Designing the foundation for the overturning motions is accomplished utilizing the computer program presented in Section 5. As noted in Section 6.2.4, the bearing pressure-time history is included in the printed output of the program.

The foundation is designed to resist the peak bearing pressures generated as the structure responds to the blast loads. The foundation is usually a very stiff element and, therefore, the time required for the bearing pressures to build to a peak is much greater than the period of the element. Consequently, the foundation must be capable of resisting the full load developed in the soil. If the foundation were less rigid, it would not provide sufficient strength to resist the overturning. Sometimes a trade-off between the length of the extension and the magnitude of the gross rotations can be made which will result in larger rotations but a thinner foundation slab.

The procedure and criteria for designing the foundation to resist the bearing pressures in the soil are presented in Appendix C. Included also are design examples which illustrate the procedure. The procedure is applicable primarily to the design of protective structures (such as cantilever wall barriers and single cell cubicles) where the stability of the structure is a critical factor.

Briefly, the procedure calls for designing the foundation for the range of properties (specified in Tables 1 and 2 of Section 4) for the particular soil at the construction site. This is done because the soils data normally available to the designer is at best a gross estimate of the actual properties. Therefore, the soil conditions producing the largest overturning motions and foundation loadings have to be considered in the design.

In some situations where soil stresses are quite large, backup structural elements may be required to support the foundation. This condition usually occurs in the design of very tall structures where the simple type foundation slab would be excessively long and thick. In these cases, buttress walls and foundation beams can be provided to reduce the slab thickness. An example of this is shown in Figures C.4 and C.5 of the Appendix. These elements must be designed for the reactions of the foundation slab when the peak bearing pressures are developed beneath the structure.

The design of foundations for protective structures must also satisfy conventional design criteria. The conventional criteria, applicable to the normal working load condition (dead and, if applicable, live load), limits the total settlement of the structure and attempts to eliminate differential settlements in various parts of the structure. To satisfy this criteria, it is necessary that the structure foundation: (1) transmit the load of the structure to a soil stratum of sufficient strength; and (2) spread the load over a sufficiently large area of that stratum to minimize the bearing pressure. If an adequate soil is not found immediately below the structure, deep foundations such as piles, are used to transmit the load to deeper firmer layers.

Generally, the foundation of a protective structure designed for the effects of the blast on the structure, will meet the requirements of the conventional criteria. However, situations may arise in which the conventional criteria will control the design of the foundation. An example of this is the structure of Example C.2 of Appendix C. In this problem, the plan size of the foundation is dictated by the requirement for maintaining the bearing pressure below the specified allowable bearing pressure under the weight of the structure. As a result, the foundation extension required is larger than that which is needed to prevent the structure from overturning.

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APPENDIX A

PROCEDURE FOR CALCULATING THE AVERAGE IMPULSE LOAD
ON
THE FOUNDATION SLAB OF A CANTILEVER WALL BARRIER

A.1 General

This appendix presents the data and the procedure for computing the average impulse loads on the foundation slab of a cantilever wall barrier.

The method of calculating the average blast impulses was developed by using a theoretical procedure based on semi-empirical blast data and on the results of response tests of reinforced concrete slabs.

The parameters which are necessary to determine the average impulse loads are the structure size, charge weight and charge location. Figure A.1 shows the parameters necessary to determine the average impulse loads.

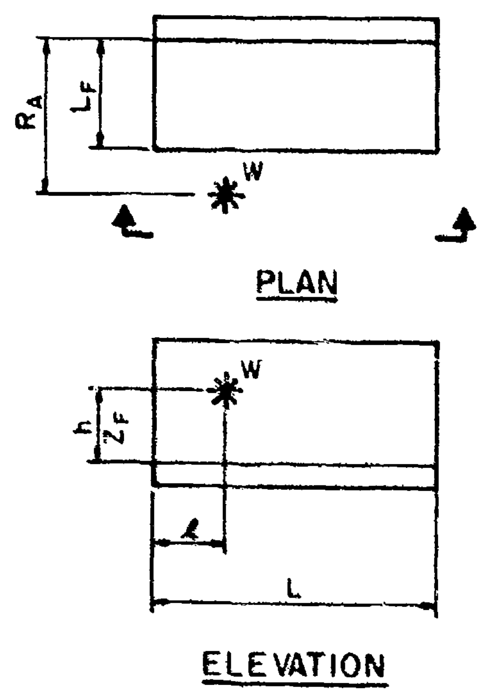

Figure A.1 Cantilever wall barrier configuration and parameters.

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Because of the wide range of required parameters, the procedure for the determination of the impulse loads was programmed for solution on a digital computer. The results of these calculations, presented in Figures A.2 through A.13, give the scaled average unit blast impulse $\bar{i}_b$ as a function of the parameters defined in Figure A.1. Each illustration is for a particular combination of values of l/L and L/L_F.

Because of the limitation in the range of the test data and the limited number of values of the parameters given in the impulse charts, extrapolation of the data given in Figures A.2 through A.13 may be required for some of the parameters involved. On the other hand, the limiting values as given in the charts for other parameters will not require extrapolation. The following are recommended procedures which will be applicable in most cases for either extrapolation, or establishing the limits of impulse loads corresponding to values of the various parameters which exceed the limits of the charts:

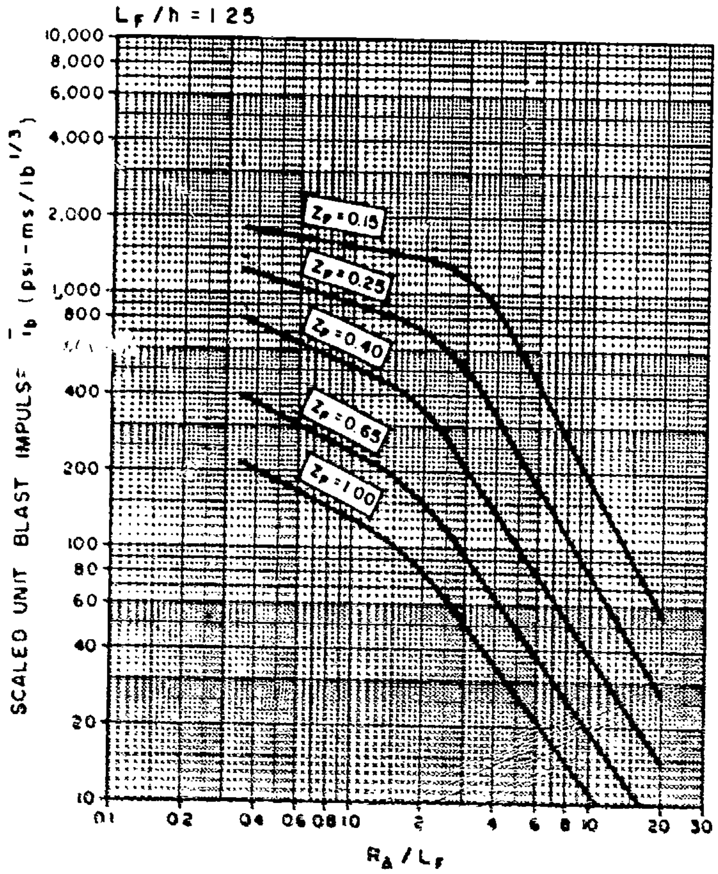
a. Plot curve of values of $\bar{i}_b$ versus Z_F for constant values of R_A/L_F, L_F/h, L/L_F and l/L. Extrapolate the curve to include the value of $\bar{i}_b$ corresponding to the value of Z_F required.

b. Extrapolate given curve for constant values of Z_F, L_F/h, L/L_F and l/L, to include value of $\bar{i}_b$ corresponding to the value R_A/L_F required.

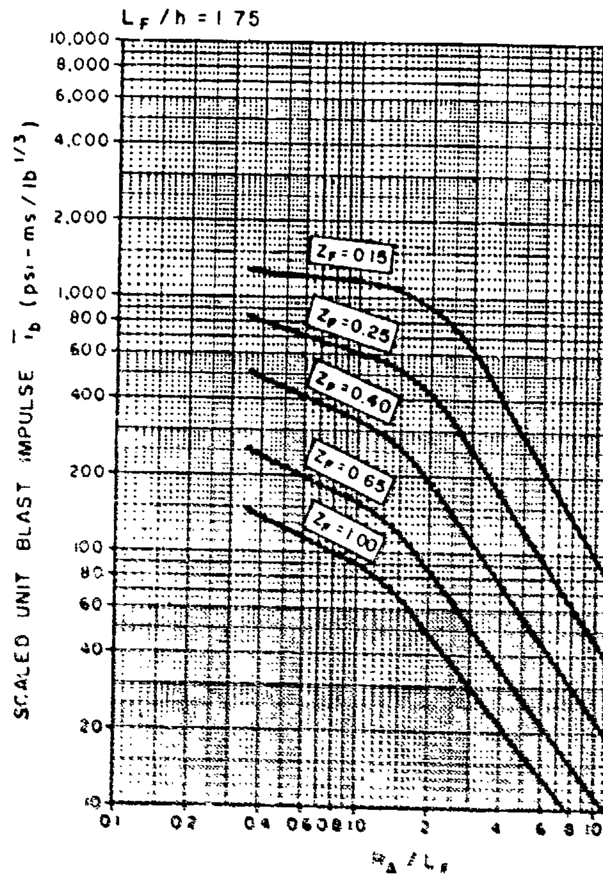
c. Plot curve of values of $\bar{i}_b$ versus L_F/h for constant values of R_A/L_F, Z_F, L/L_F and l/L. Extrapolate curve to include value of $\bar{i}_b$ corresponding to the value of L_F/h required.

d. Plot curves of values of $\bar{i}_b$ versus L/L_F for constant values of R_A/L_F, Z_F, L_F/h and l/L. Extrapolate curve to include value of $\bar{i}_b$ corresponding to the value of L/L_F required.

e. Values of $\bar{i}_b$ corresponding to values of l/L less than 0.10 shall be taken as equal to those corresponding to $l/L = 0.10$.



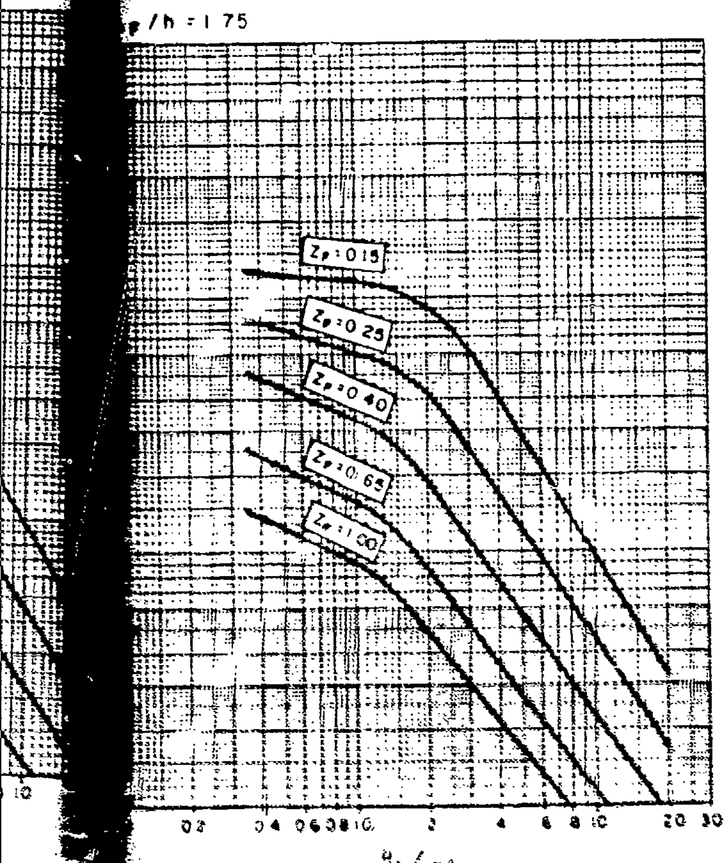
$L_F/h = 1.25$
SCALED UNIT BLAST IMPULSE $\bar{i}_b$ (psi-ms/lb$^{1/3}$)
R_A/L_F
$Z_F = 0.15$
$Z_F = 0.25$
$Z_F = 0.40$
$Z_F = 0.65$
$Z_F = 1.00$

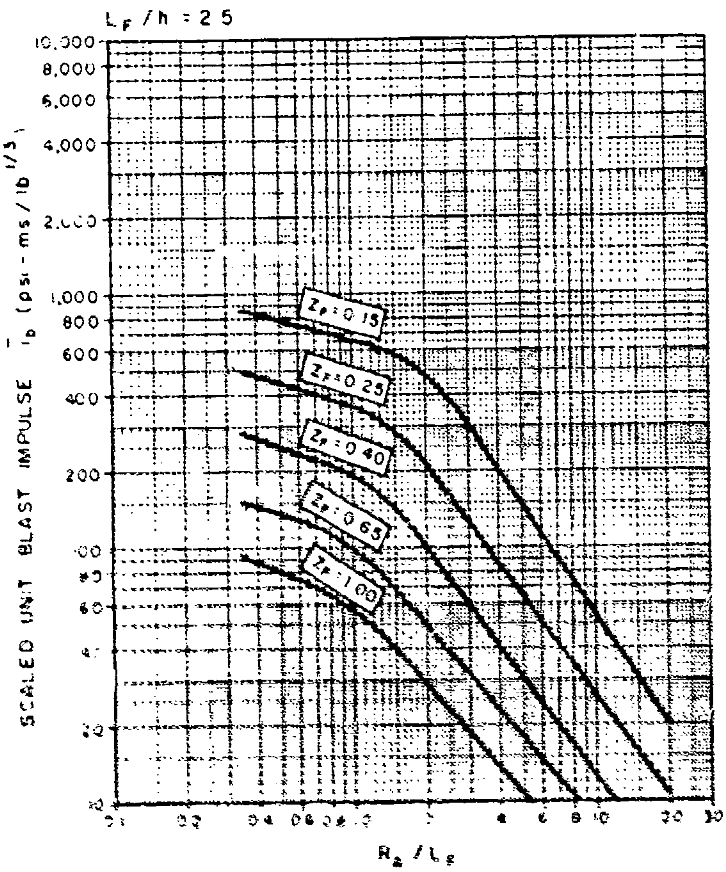


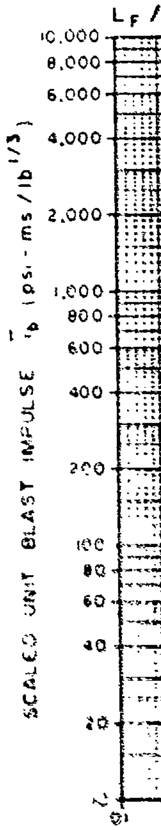
$L_F/h = 1.75$
SCALED UNIT BLAST IMPULSE $\bar{i}_b$ (psi-ms/lb$^{1/3}$)
R_A/L_F
$Z_F = 0.15$
$Z_F = 0.25$
$Z_F = 0.40$
$Z_F = 0.65$
$Z_F = 1.00$

Scaled av

aver

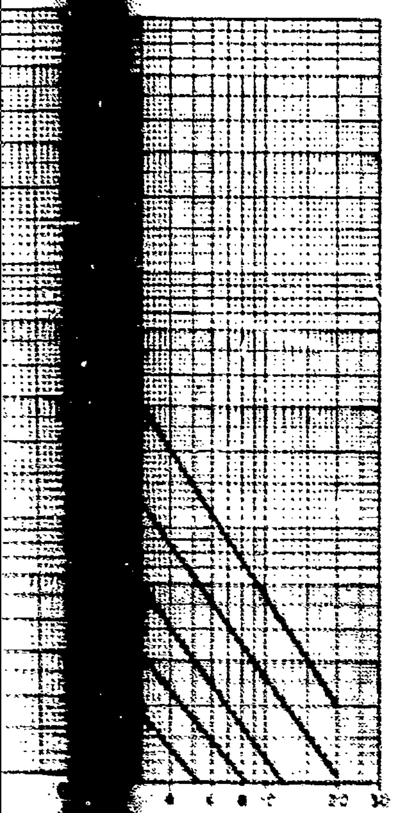


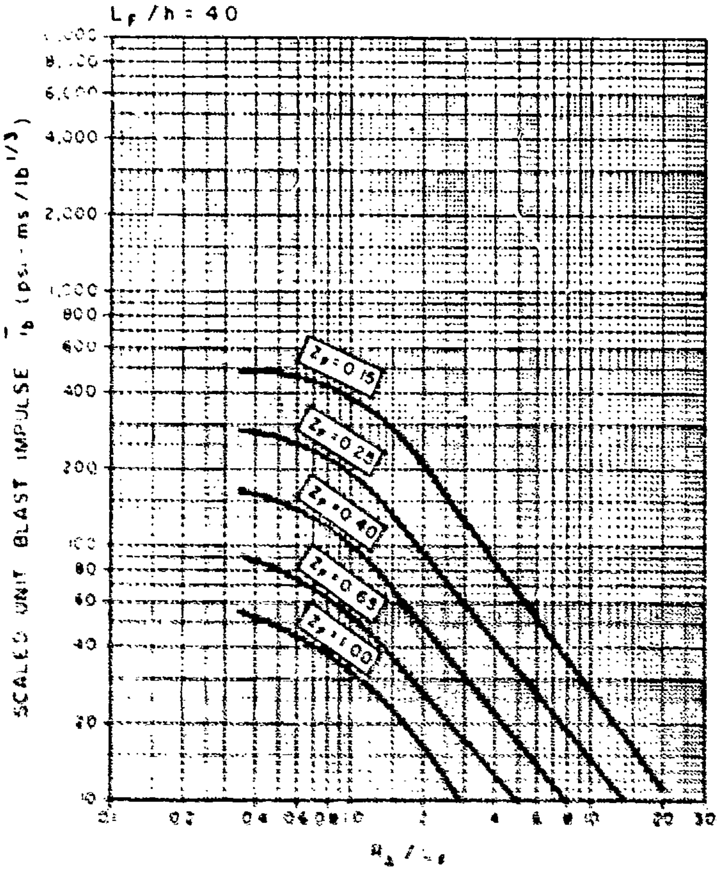




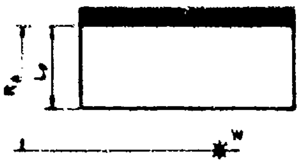
Scaled average unit blast impulse (L/L_F=1.0,Z/L=0.10)

2

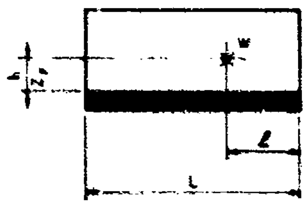




PARAMETERS



PLAN



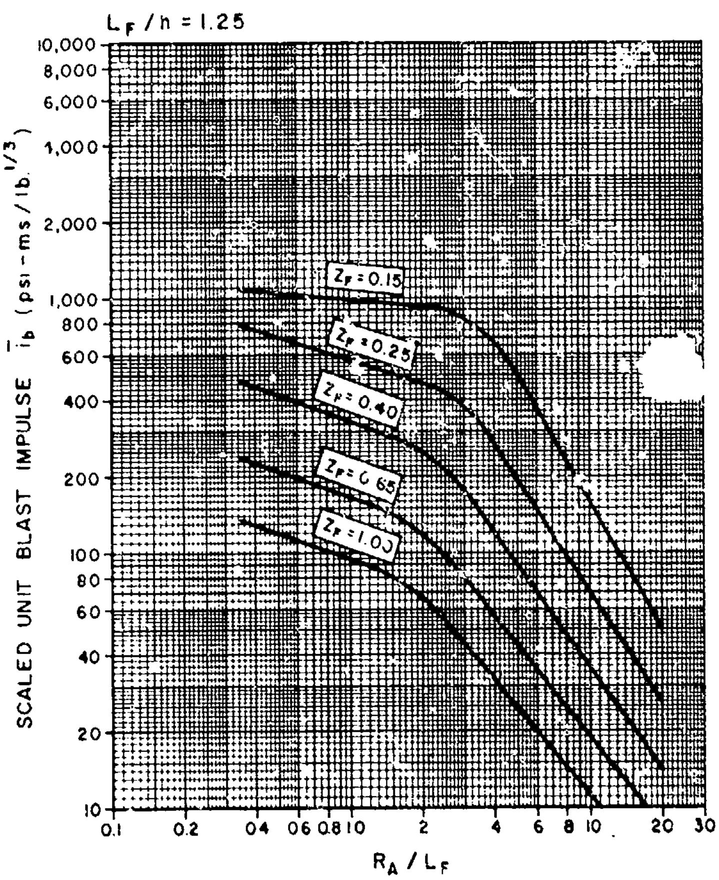
ELEVATION

$\frac{L}{L_F} = 1.0$

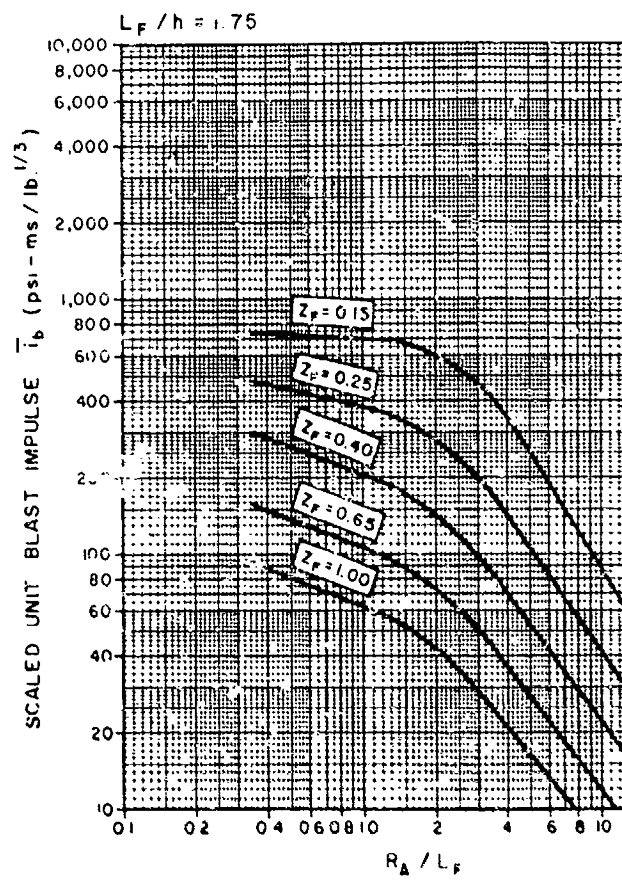
$\frac{\ell}{L} = 0.1$

FIGURE A2

3

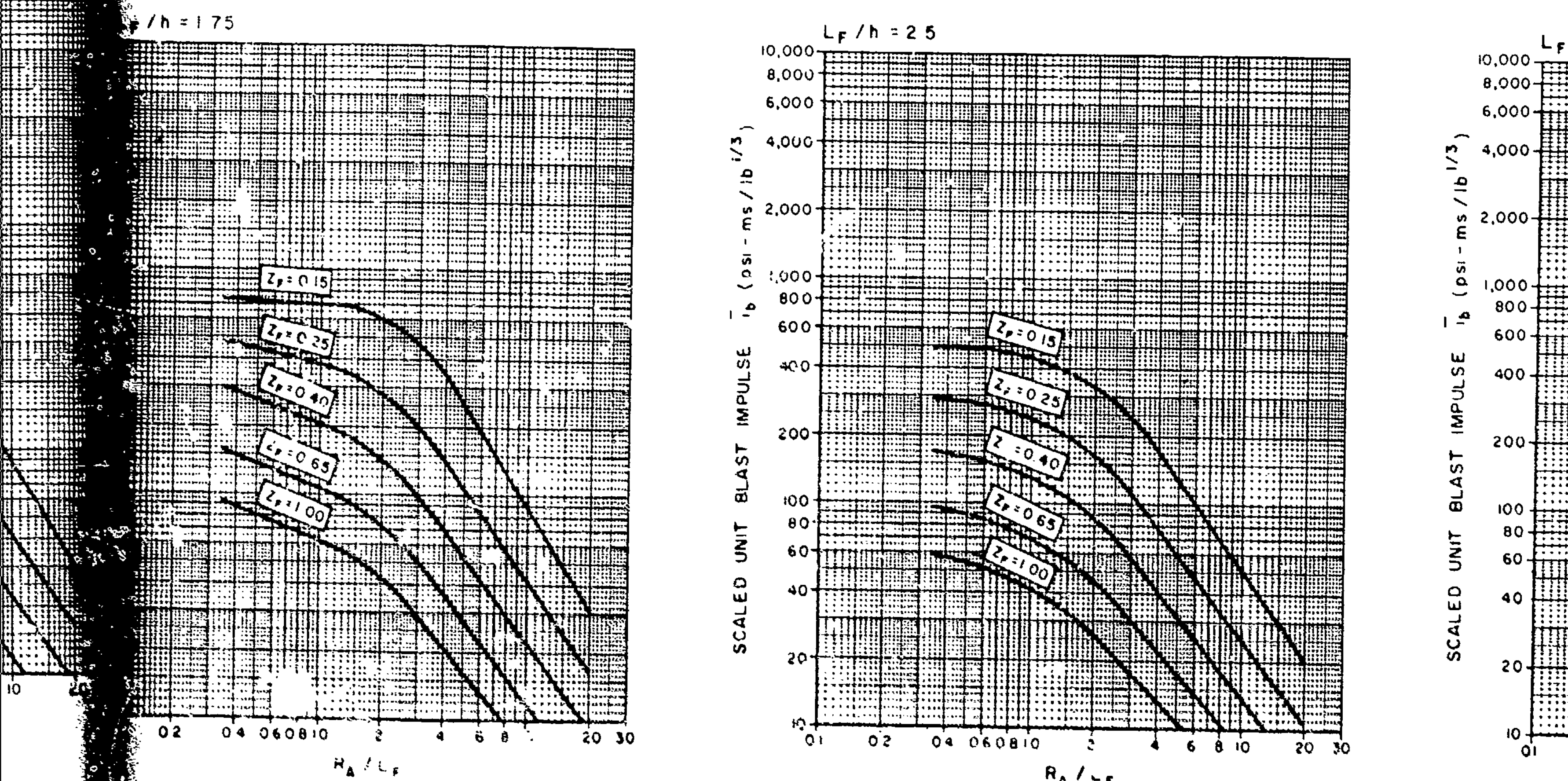


L_F / h = 1.25
SCALED UNIT BLAST IMPULSE ī_b (psi-ms / lb.^1/3)
10,000
8,000
6,000
4,000
2,000
1,000
800
600
400
200
100
80
60
40
20
10
Z_F = 0.15
Z_F = 0.25
Z_F = 0.40
Z_F = 0.65
Z_F = 1.00
0.1
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
20
30
R_A / L_F



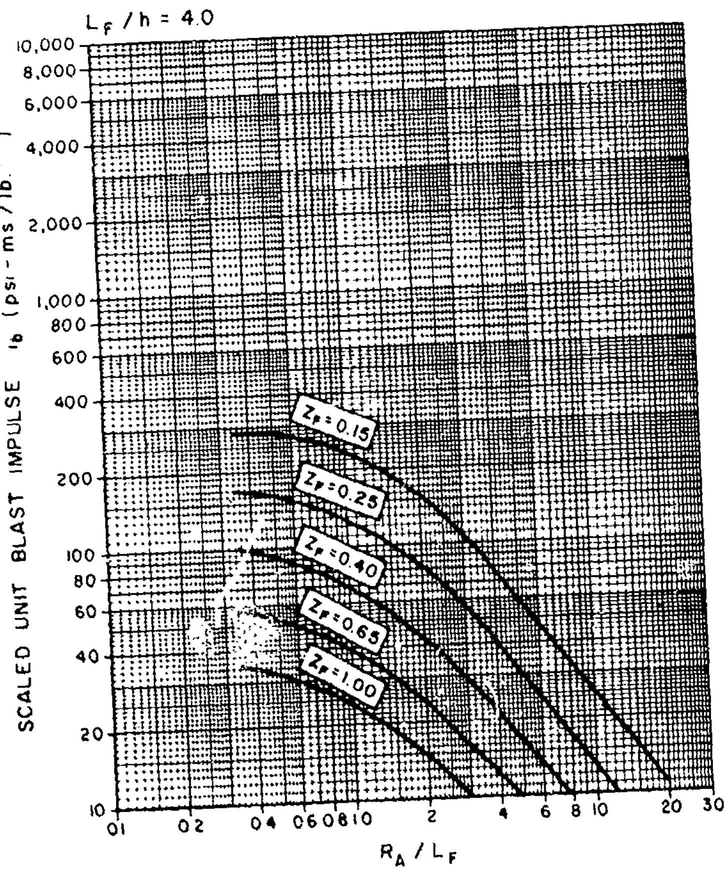
L_F / h = 1.75
SCALED UNIT BLAST IMPULSE ī_b (psi-ms / lb.^1/3)
10,000
8,000
6,000
4,000
2,000
1,000
800
600
400
100
80
60
40
20
10
Z_F = 0.15
Z_F = 0.25
Z_F = 0.40
Z_F = 0.65
Z_F = 1.00
0.1
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
R_A / L_F

Scalec



led ave

Scaled average unit blast impulse $(L/L_F=3.0, Z/L=0.10)$



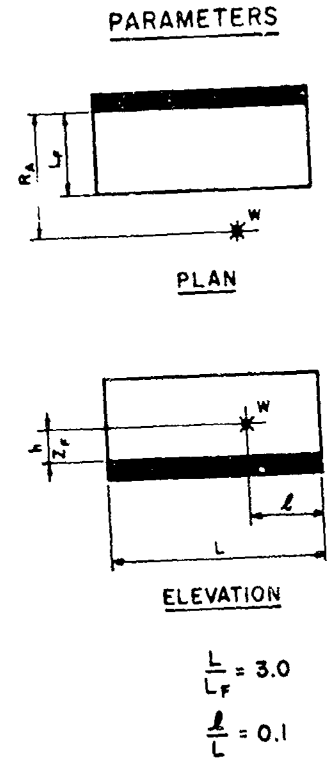


FIGURE A.3

3

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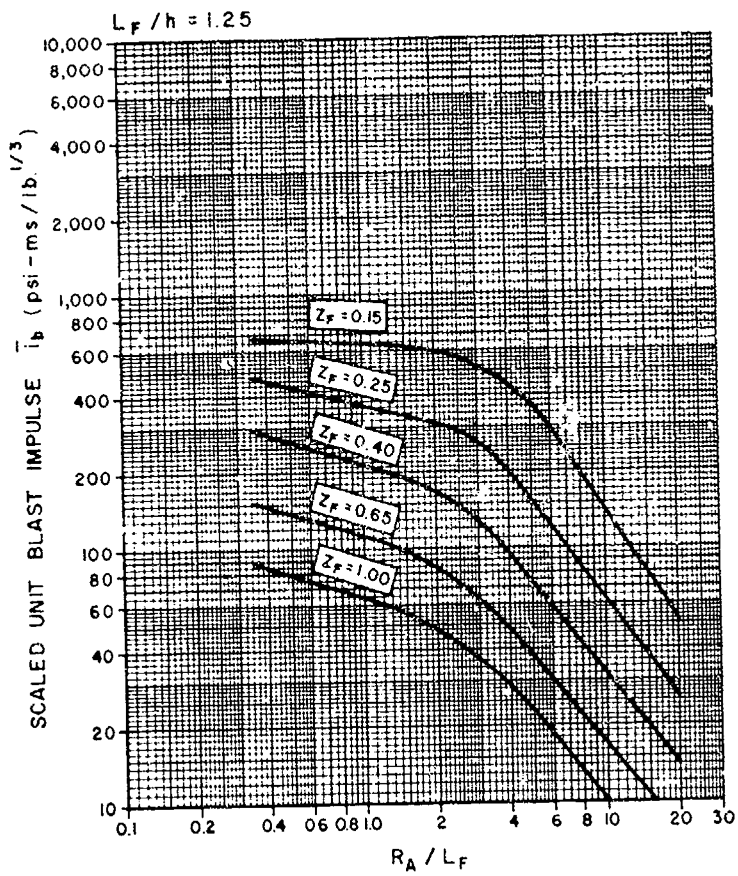
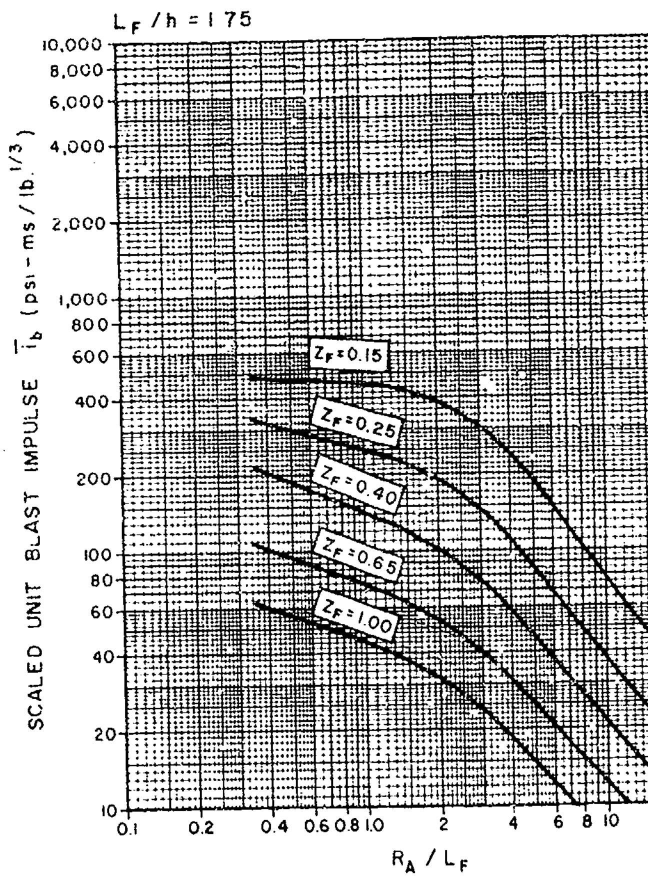
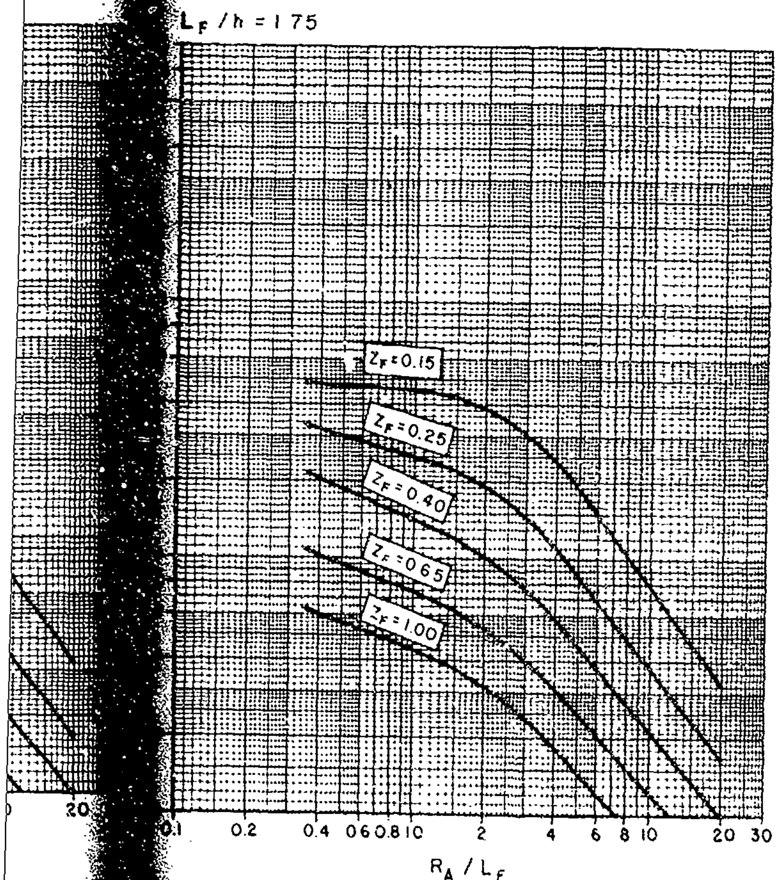


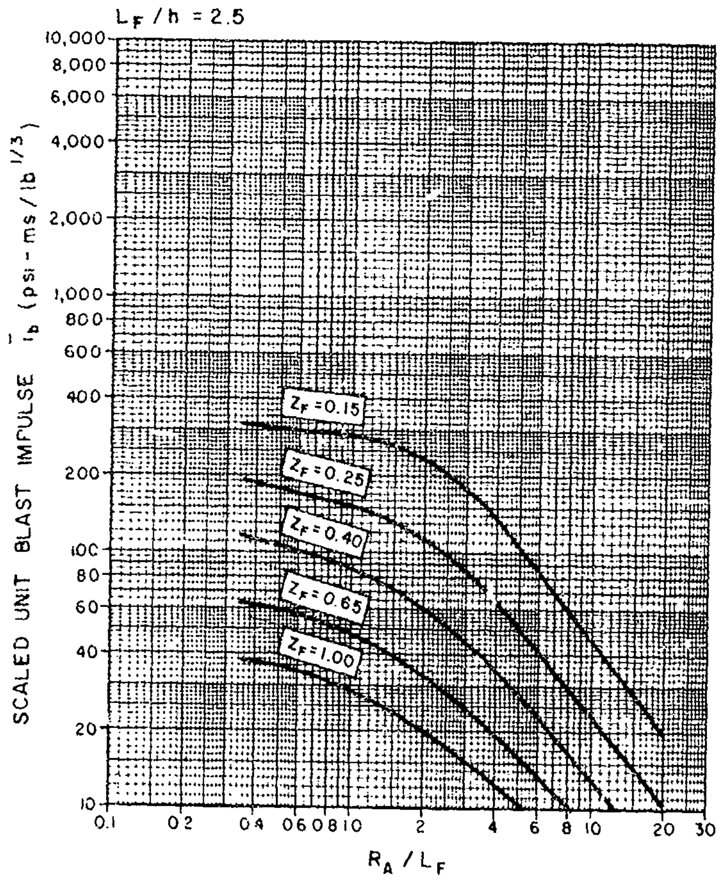
L_F / h = 1.25
SCALED UNIT BLAST IMPULSE i_b (psi-ms / lb.^1/3)
Z_F = 0.15
Z_F = 0.25
Z_F = 0.40
Z_F = 0.65
Z_F = 1.00
R_A / L_F

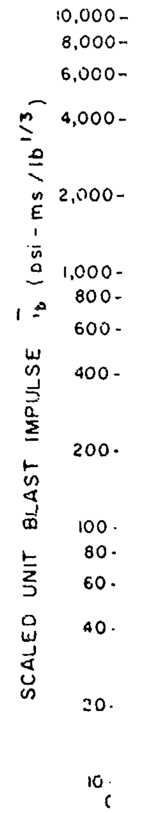


L_F / h = 1.75
SCALED UNIT BLAST IMPULSE i_b (psi-ms / lb.^1/3)
Z_F = 0.15
Z_F = 0.25
Z_F = 0.40
Z_F = 0.65
Z_F = 1.00
R_A / L_F

Scaled



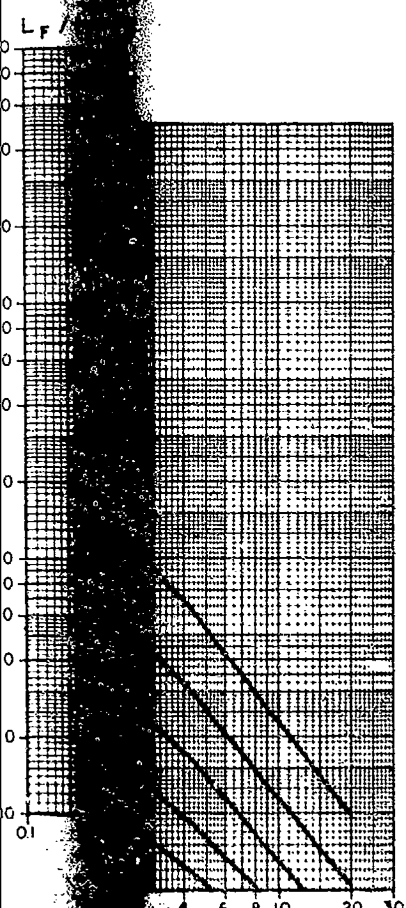




ed ave

Scaled average unit blast impulse (L/L_F=6.5, Z/L=0.10)

2



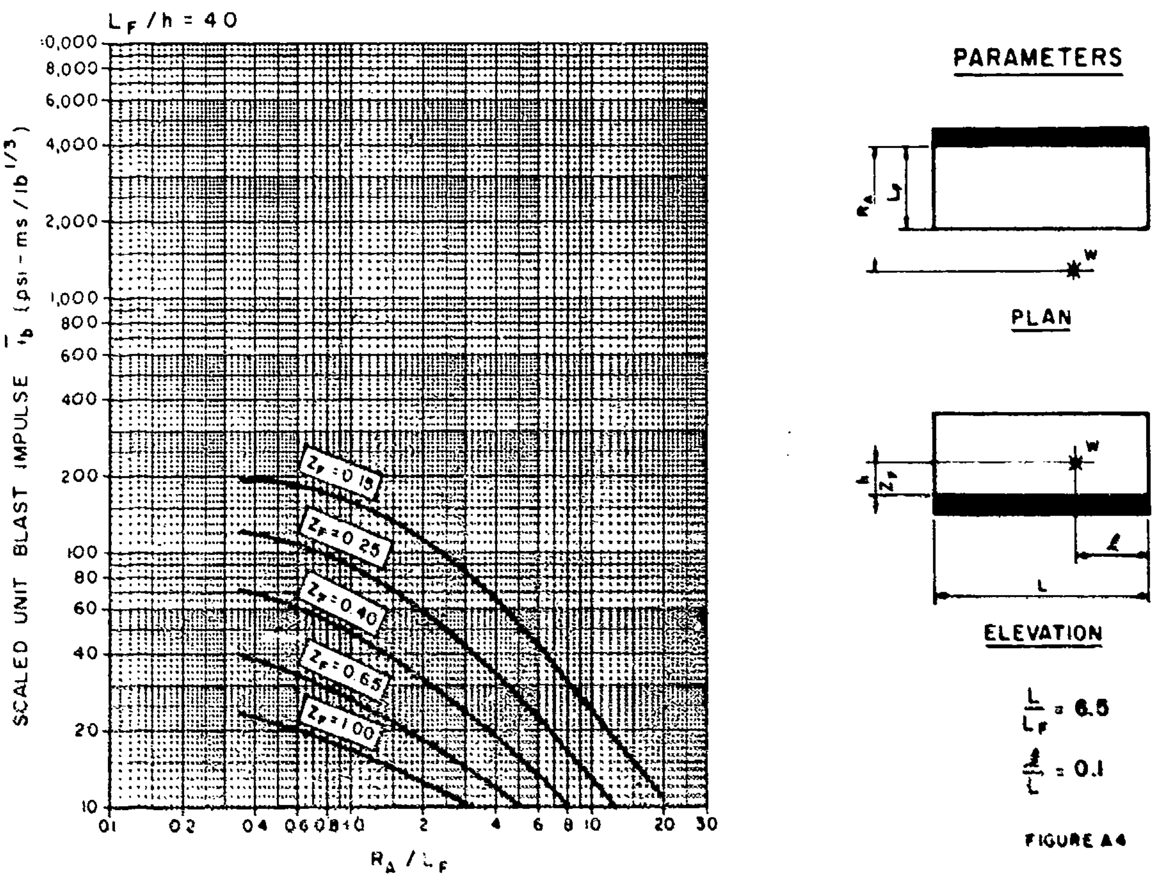


FIGURE A4

10)

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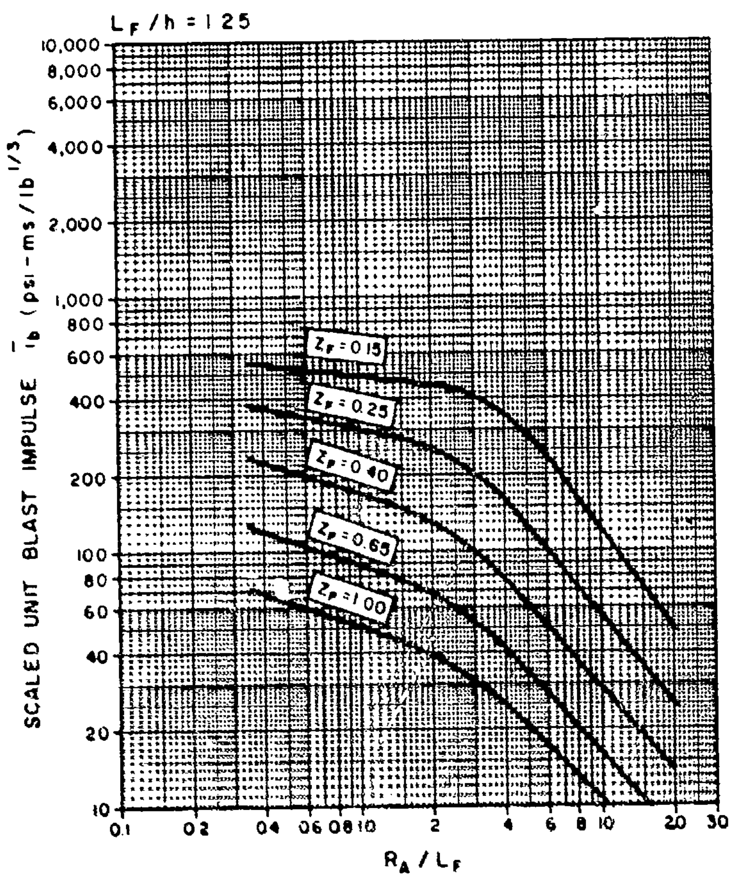
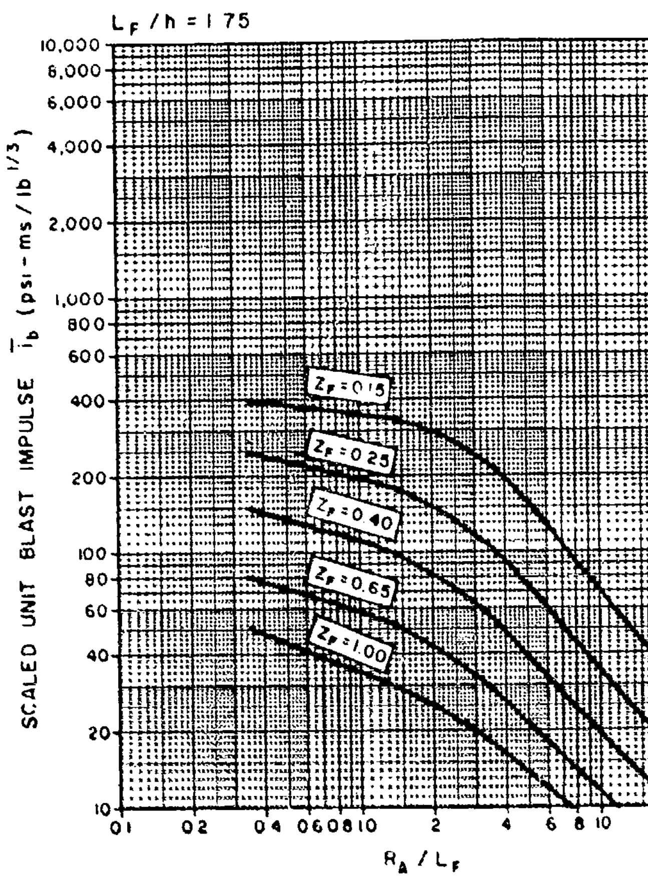
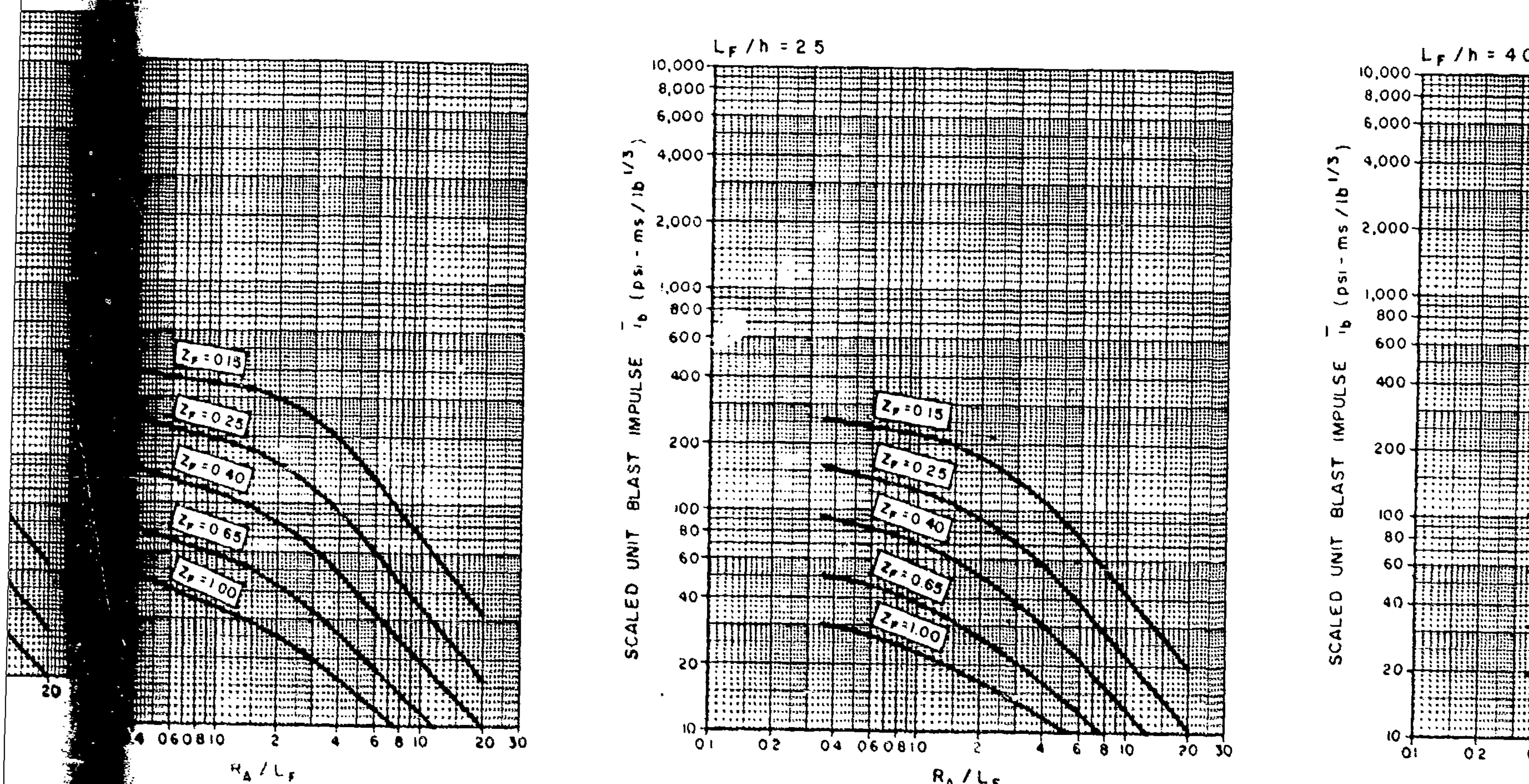


L_F / h = 1.25
SCALED UNIT BLAST IMPULSE ī_b (psi-ms/lb^1/3)
10,000
8,000
6,000
4,000
2,000
1,000
800
600
400
200
100
80
60
40
20
10
Z_F = 0.15
Z_F = 0.25
Z_F = 0.40
Z_F = 0.65
Z_F = 1.00
0.1
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
20
30
R_A / L_F



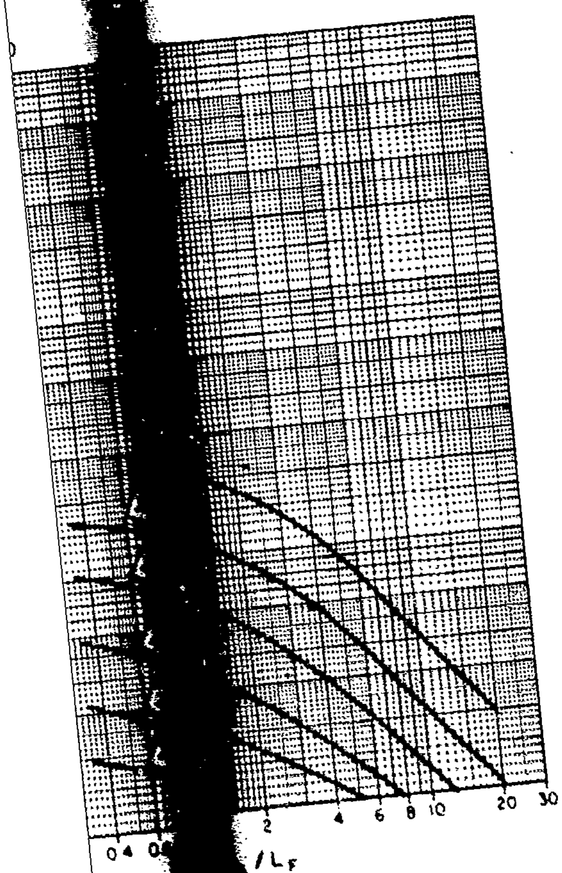
L_F / h = 1.75
SCALED UNIT BLAST IMPULSE ī_b (psi-ms/lb^1/3)
10,000
8,000
6,000
4,000
2,000
1,000
800
600
400
200
100
80
60
40
20
10
Z_F = 0.15
Z_F = 0.25
Z_F = 0.40
Z_F = 0.65
Z_F = 1.00
0.1
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
R_A / L_F

Scal

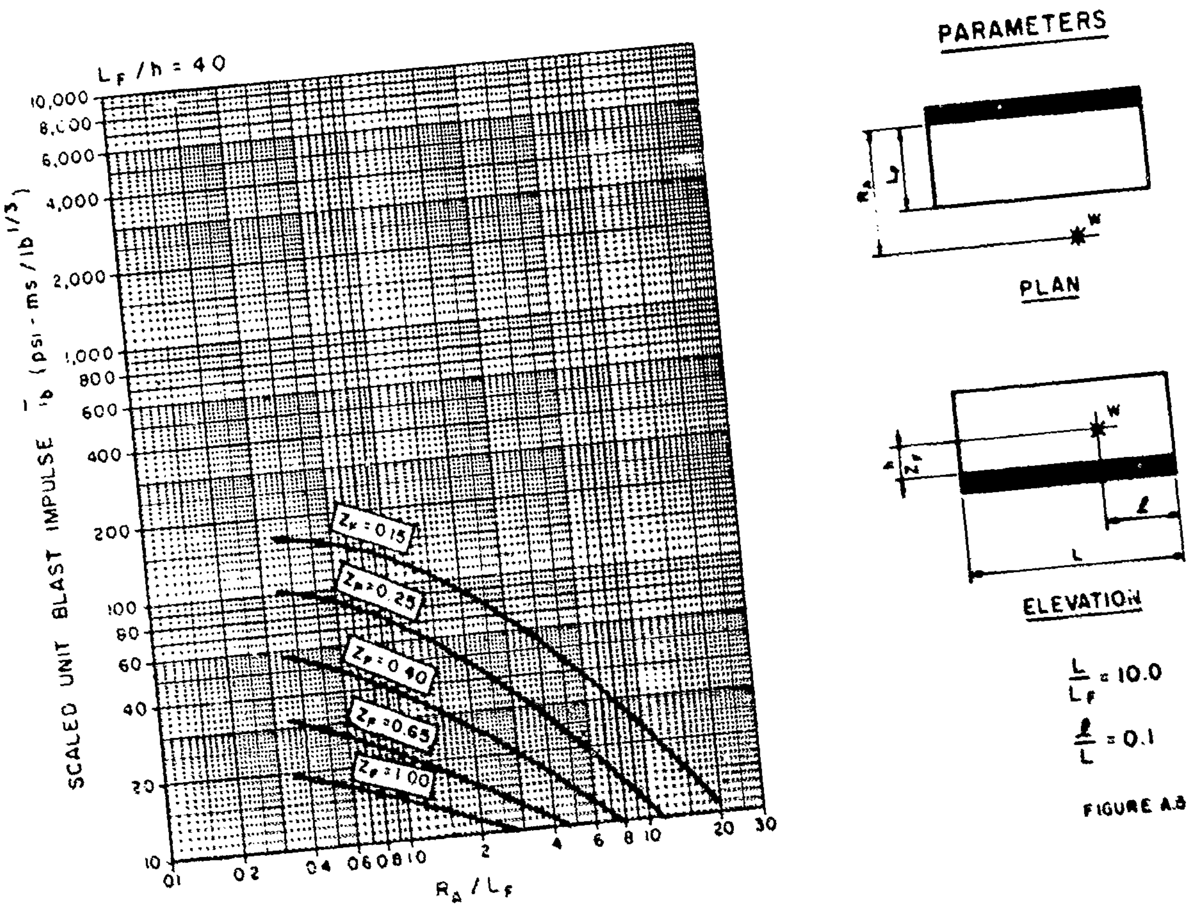


aled

Scaled average unit blast impulse (L/L_F=10.0, Z/L=0.10)



0,Z/L=0.10)



3

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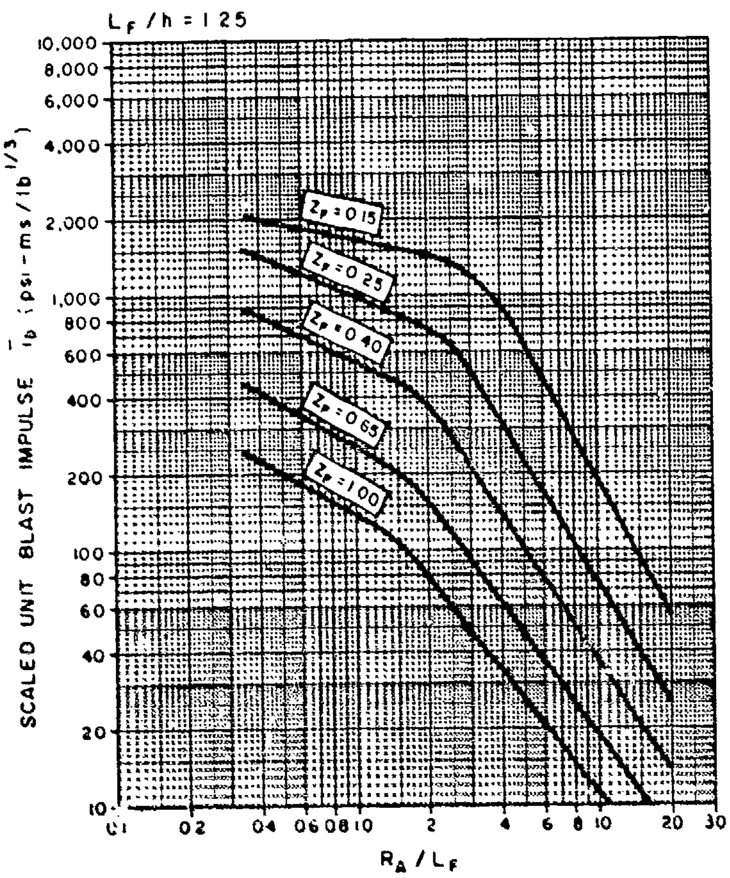
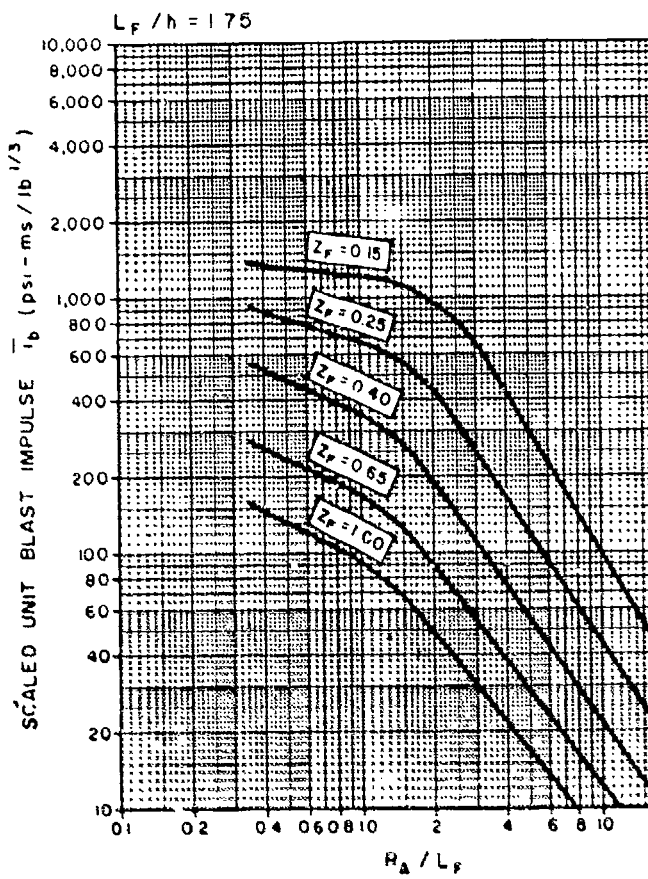
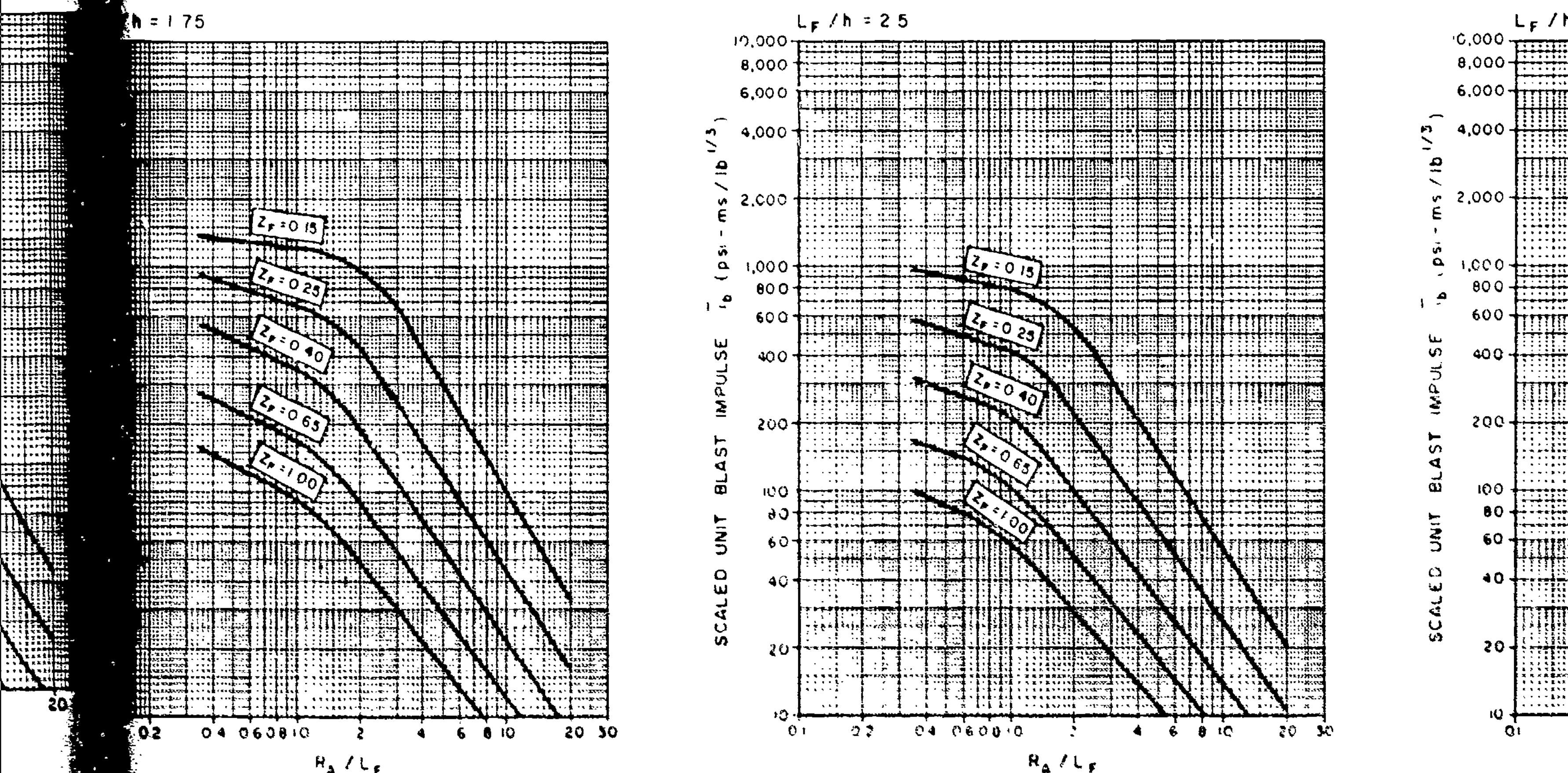


$L_F / h = 1.25$
SCALED UNIT BLAST IMPULSE $\bar{i}_b$ (psi-ms / lb$^{1/3}$)
$Z_F = 0.15$
$Z_F = 0.25$
$Z_F = 0.40$
$Z_F = 0.65$
$Z_F = 1.00$
R_A / L_F



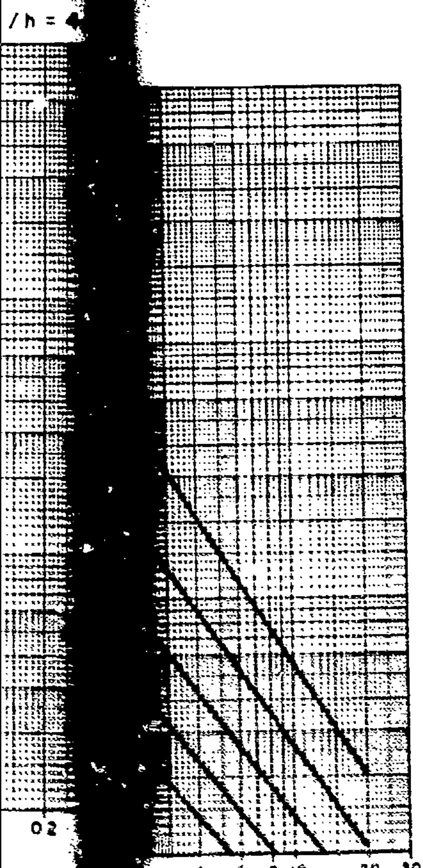
$L_F / h = 1.75$
SCALED UNIT BLAST IMPULSE $\bar{i}_b$ (psi-ms / lb$^{1/3}$)
$Z_F = 0.15$
$Z_F = 0.25$
$Z_F = 0.40$
$Z_F = 0.65$
$Z_F = 1.00$
R_A / L_F

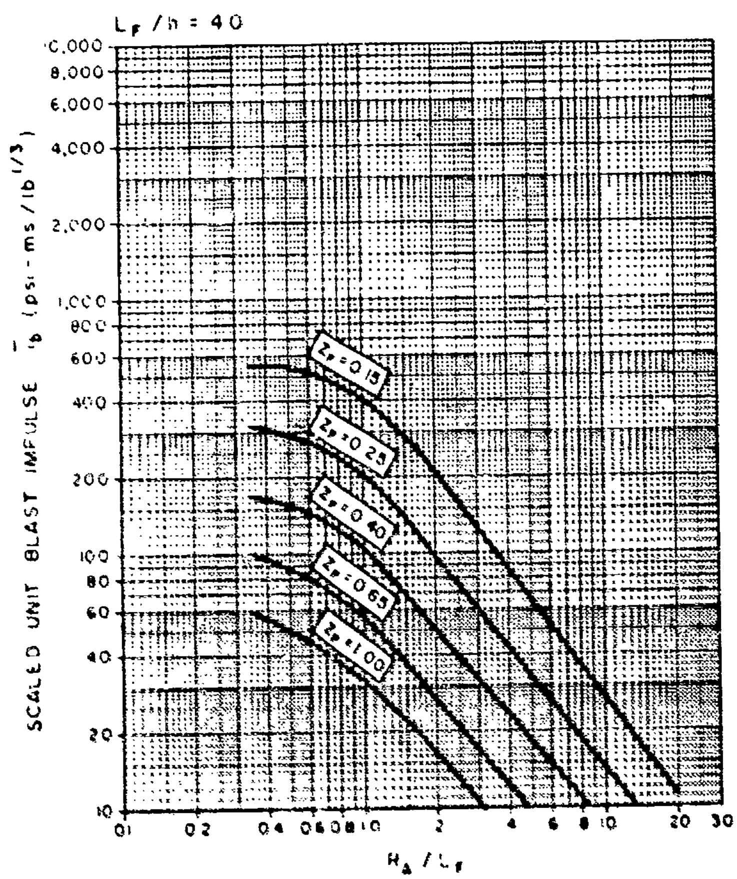
Scaled



ed ave

Scaled average unit blast impulse (L/L_F=1.0, Z/L=0.25)


/h = 4
02
4 6 8 10 20 30


L_F / h = 4.0
SCALED UNIT BLAST IMPULSE $\bar{i}_b$ (psi - ms / lb$^{1/3}$)
10,000
8,000
6,000
4,000
2,000
1,000
800
600
400
200
100
80
60
40
20
10
Z_F = 0.15
Z_F = 0.25
Z_F = 0.40
Z_F = 0.65
Z_F = 1.00
01 02 04 0608 10 2 4 6 8 10 20 30
R_A / L_F

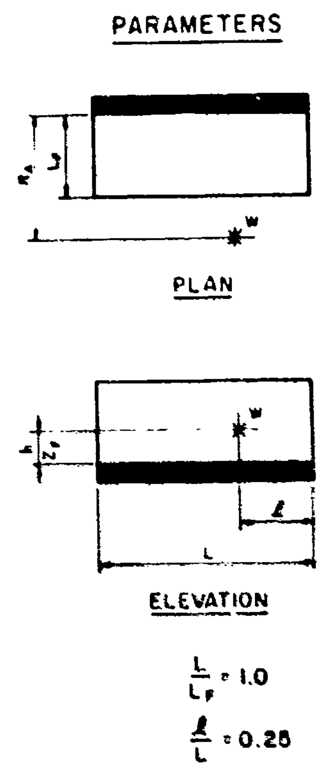
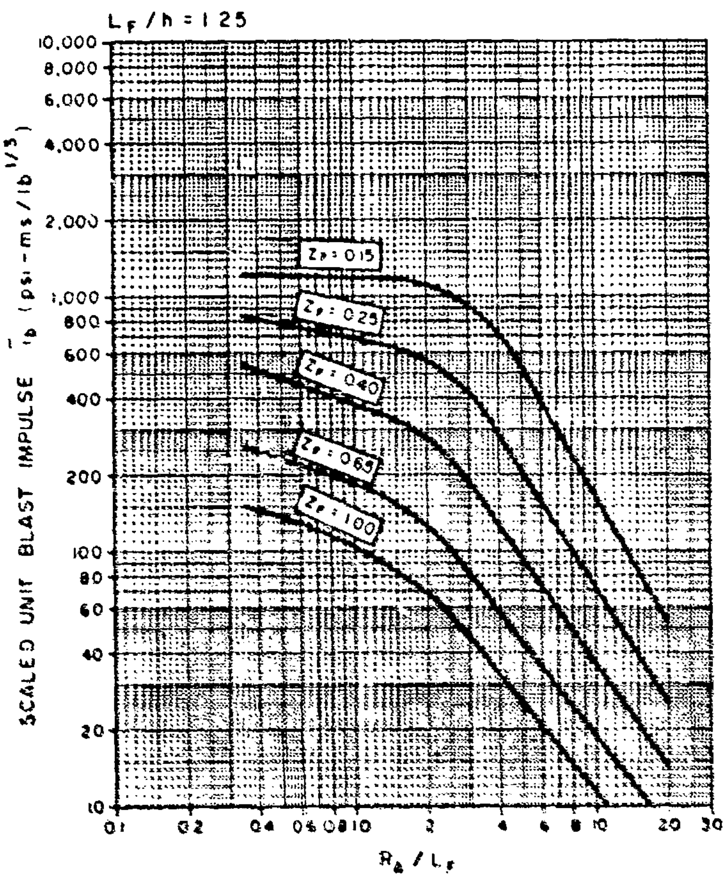
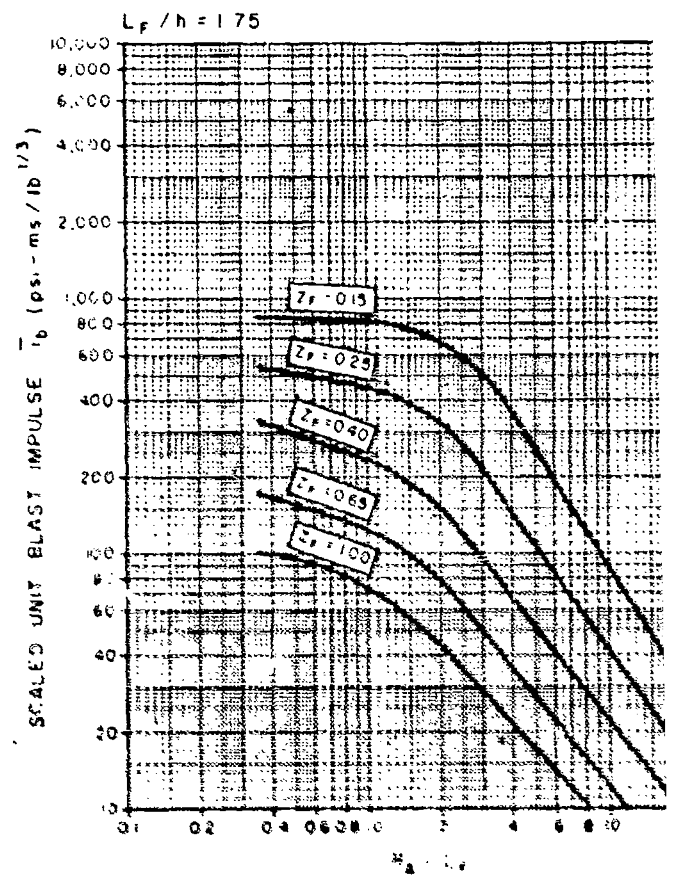

PARAMETERS
R_A
L_F
W
PLAN
W
h
Z_F
ℓ
L
ELEVATION
$\frac{L}{L_F}$ = 1.0
$\frac{\ell}{L}$ = 0.25

FIGURE A6

.25)

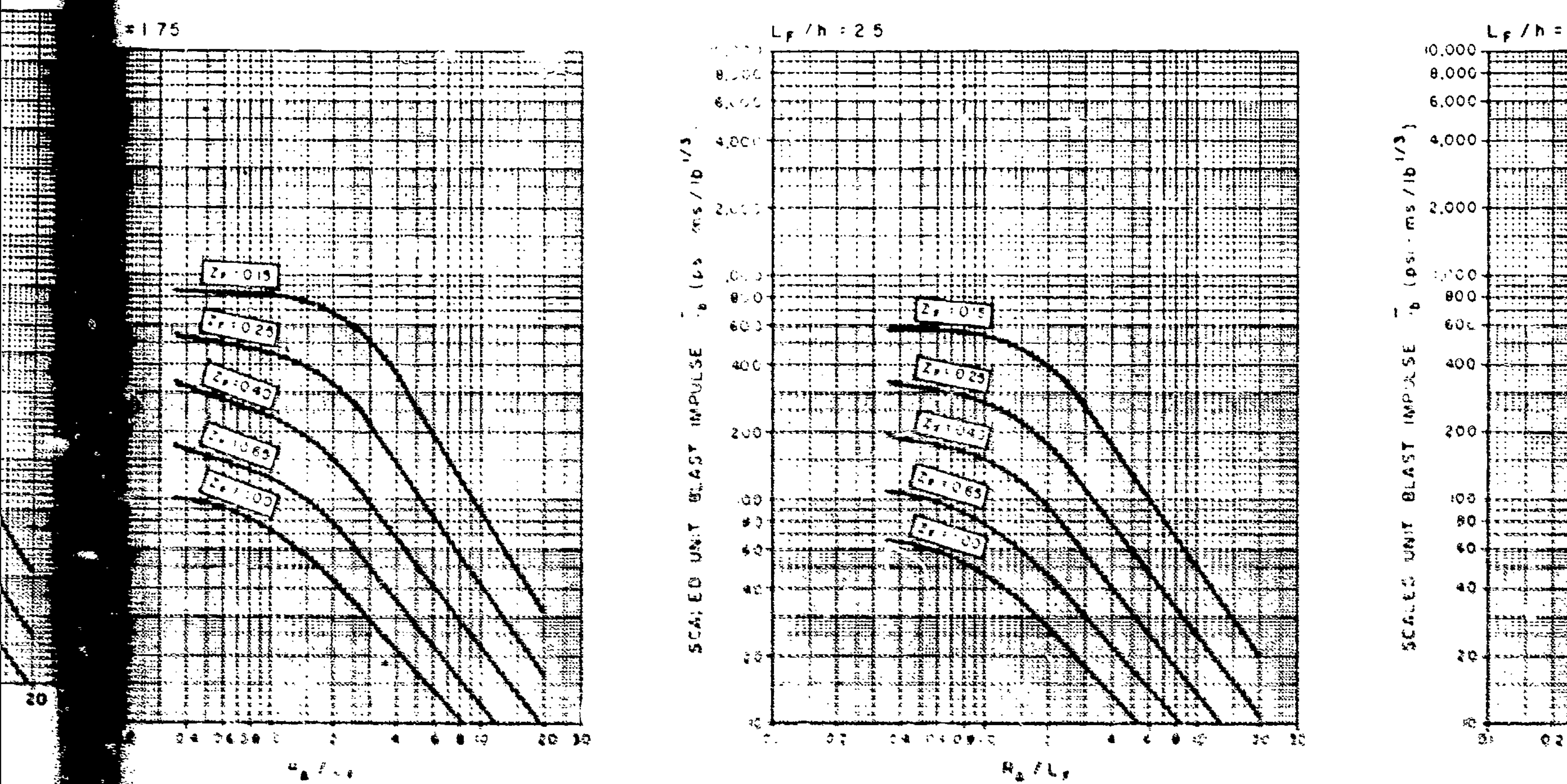


L F / h = 1.25
10,000
8,000
6,000
4,000
2,000
1,000
800
600
400
200
100
80
60
40
20
10
SCALED UNIT BLAST IMPULSE ib (psi-ms/lb 1/3)
ZF = 0.15
ZF = 0.25
ZF = 0.40
ZF = 0.65
ZF = 1.00
0.1
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
20
30
RA / LF



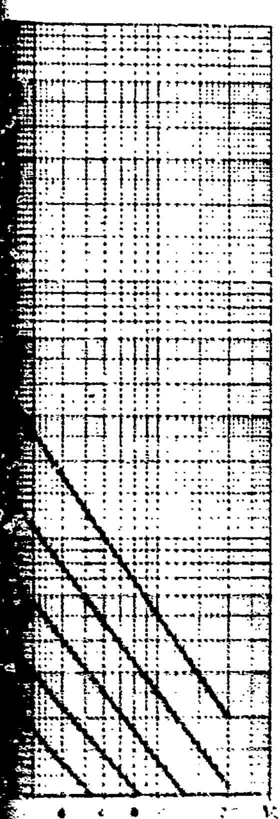
L F / h = 1.75
10,000
8,000
6,000
4,000
2,000
1,000
800
600
400
200
100
60
40
20
10
SCALED UNIT BLAST IMPULSE ib (psi-ms/lb 1/3)
ZF = 0.15
ZF = 0.25
ZF = 0.40
ZF = 0.65
ZF = 1.00
0.1
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10

Scal



aled

Scaled average unit blast impulse (L/Lf=3.0, Z/L=0.25)



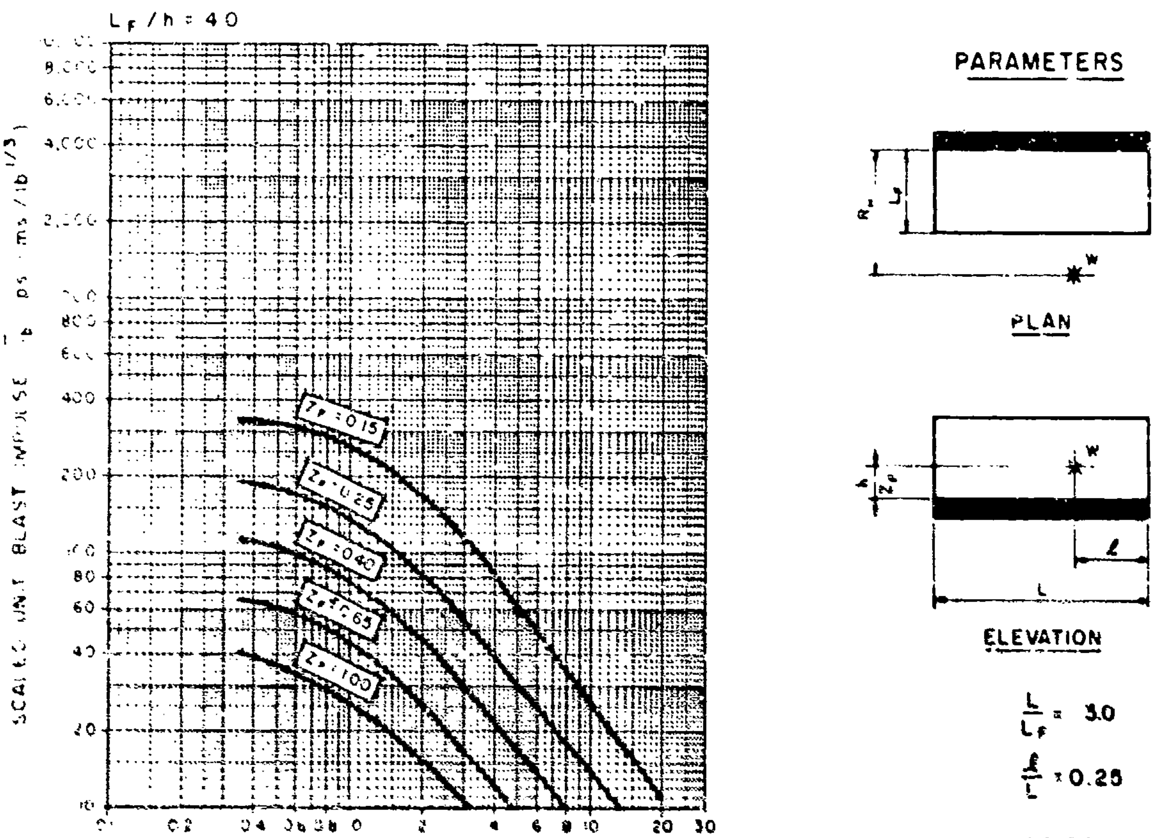


FIGURE A.7

L=0.75)

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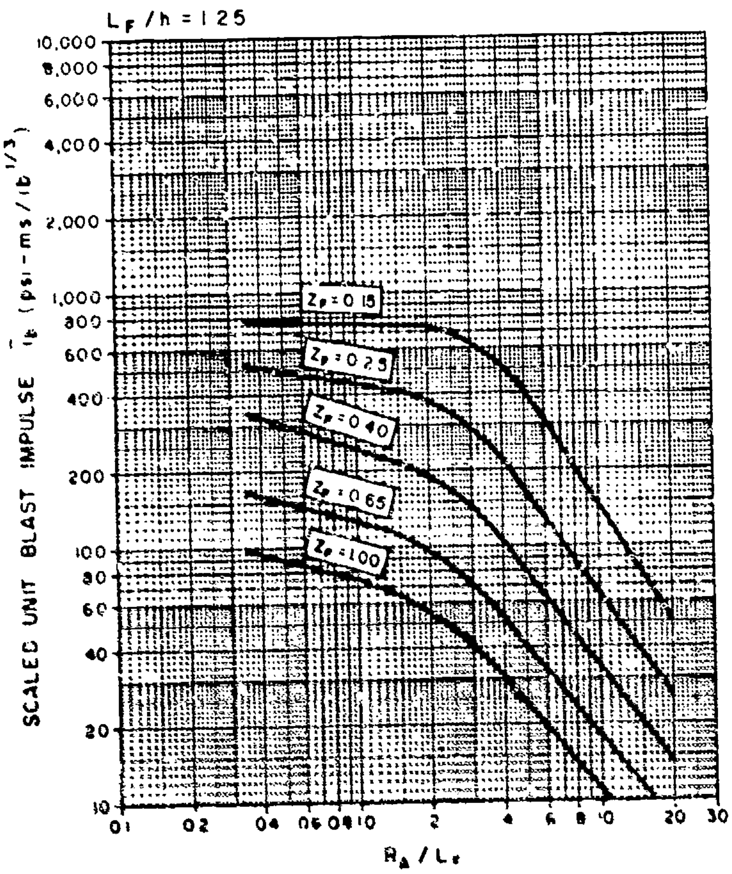
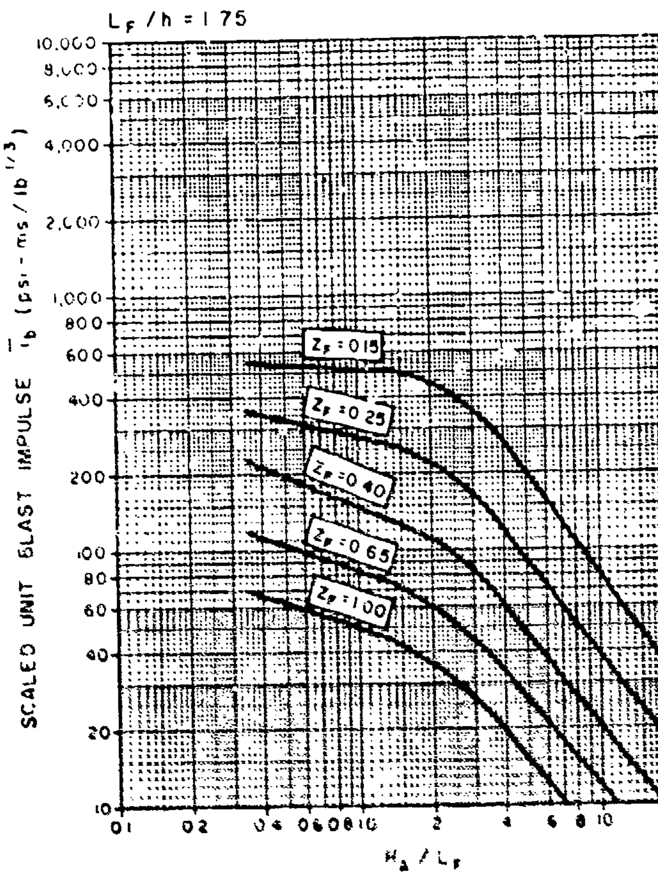
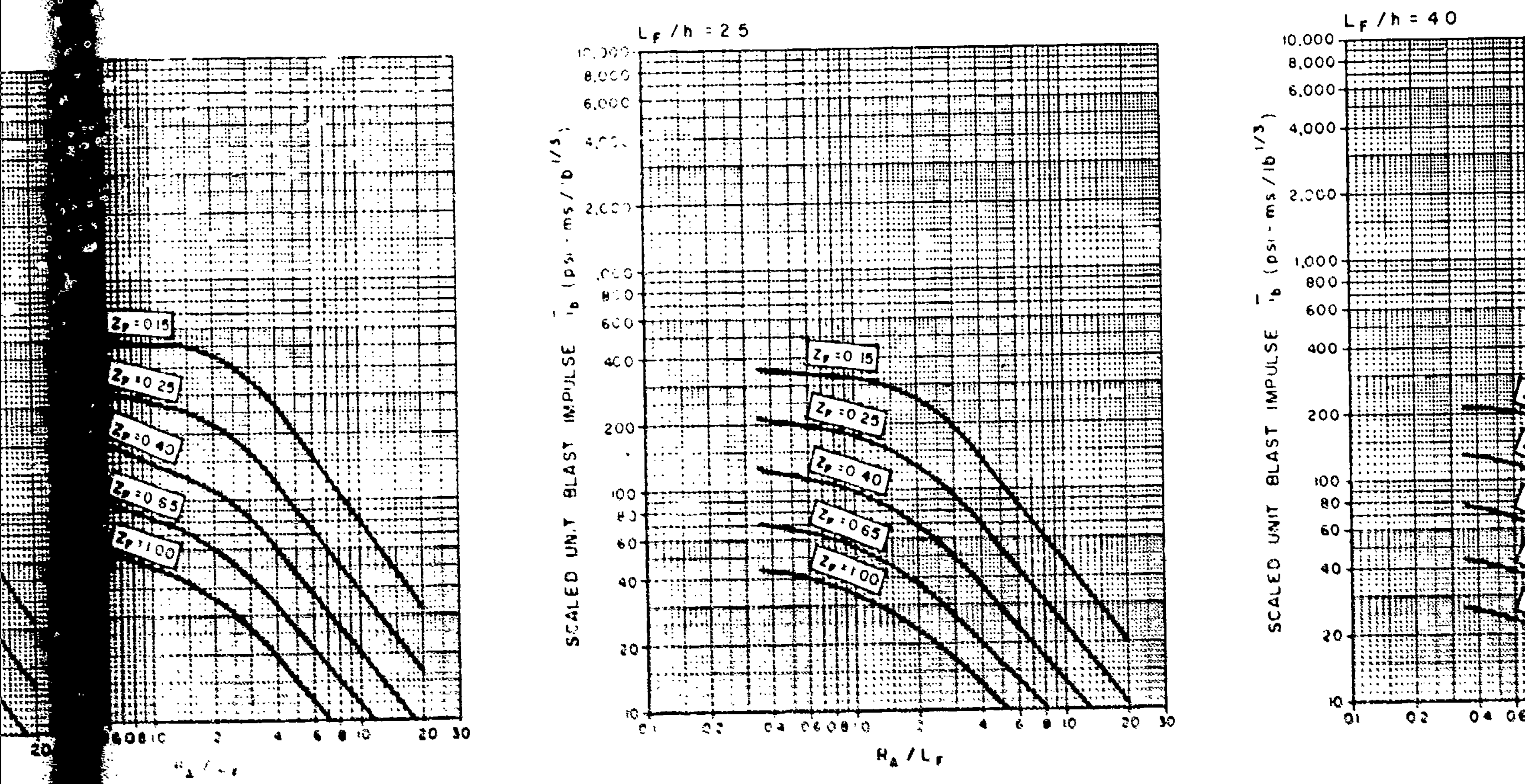




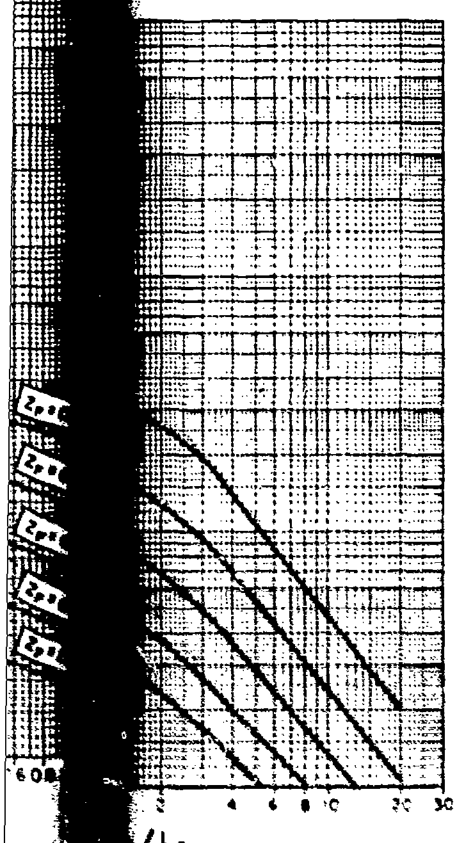
Scaled averag

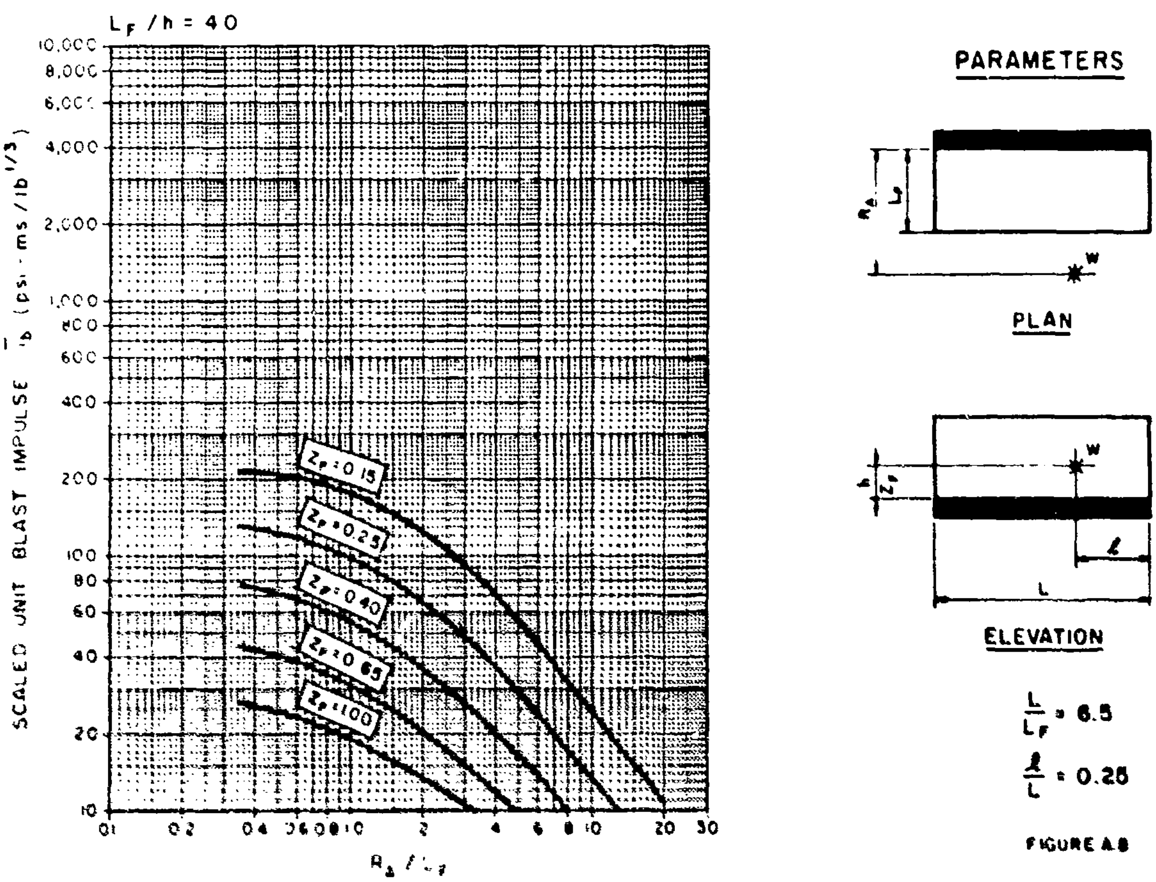


age

Scaled average unit blast impulse (L/L_F=6.5, Z/L=0.25)

2



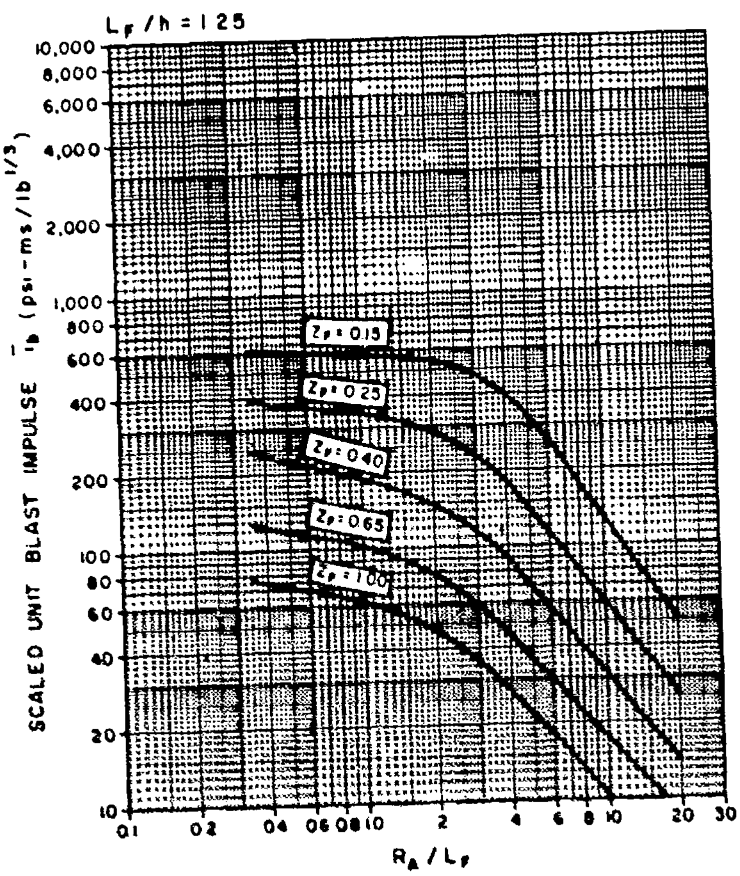


$L_F / h = 40$
SCALED UNIT BLAST IMPULSE $\bar{i}_b$ (psi - ms / lb$^{1/3}$)
10,000
8,000
6,000
4,000
2,000
1,000
800
600
400
200
100
80
60
40
20
10
$Z_P = 0.15$
$Z_P = 0.25$
$Z_P = 0.40$
$Z_P = 0.65$
$Z_P = 1.00$
0.1 0.2 0.4 0.6 0.8 1.0 2 4 6 8 10 20 30
R_A / L_F
PARAMETERS
R_A
L_F
W
PLAN
h
Z_P
W
ℓ
L
ELEVATION
$\frac{L}{L_F} = 6.5$
$\frac{\ell}{L} = 0.25$

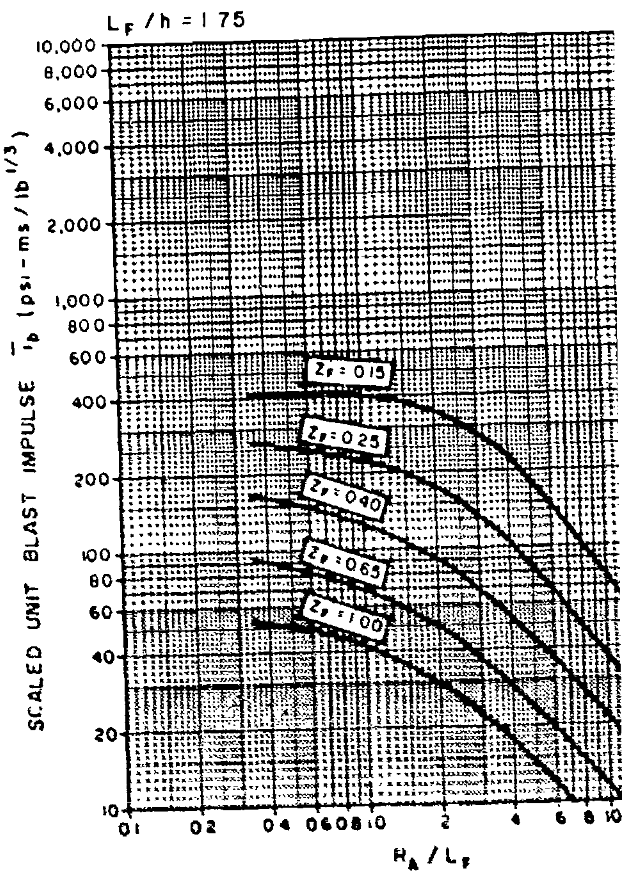
FIGURE A.8

5)

3

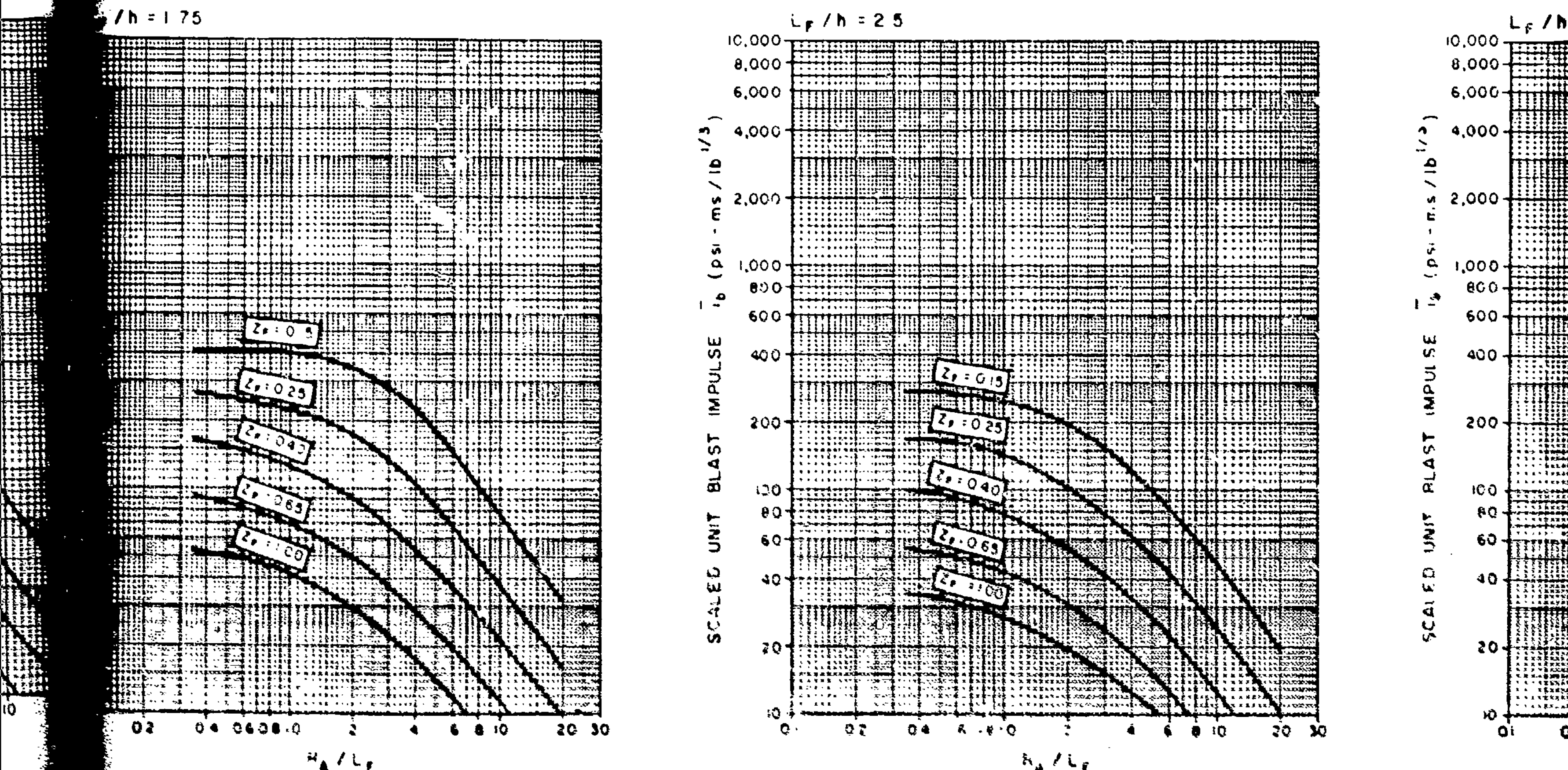


$L_F/h = 1.25$
SCALED UNIT BLAST IMPULSE $\bar{i}_b$ (psi-ms/lb$^{1/3}$)
$Z_F = 0.15$
$Z_F = 0.25$
$Z_F = 0.40$
$Z_F = 0.65$
$Z_F = 1.00$
R_A/L_F



$L_F/h = 1.75$
SCALED UNIT BLAST IMPULSE $\bar{i}_b$ (psi-ms/lb$^{1/3}$)
$Z_F = 0.15$
$Z_F = 0.25$
$Z_F = 0.40$
$Z_F = 0.65$
$Z_F = 1.00$
R_A/L_F

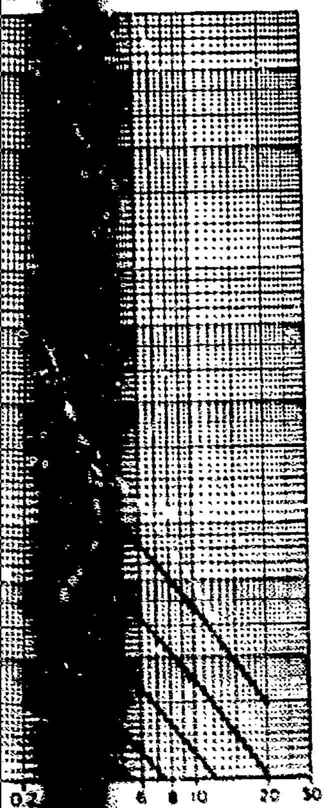
Scaled aver

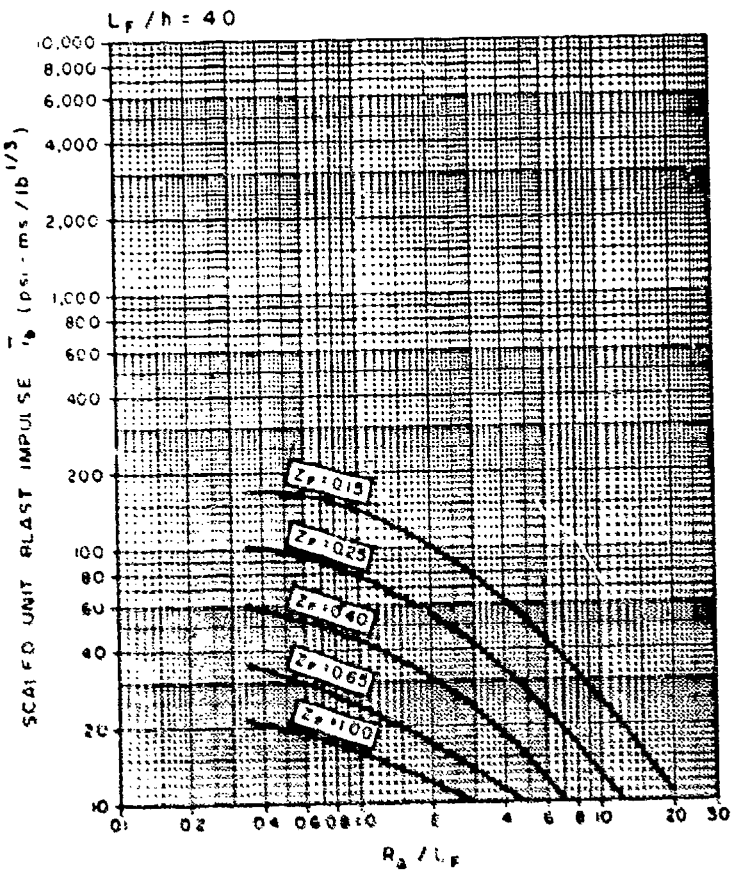


erag

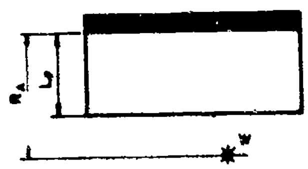
Scaled average unit blast impulse (L/L_F=10.0, Z/L=0.25)

2

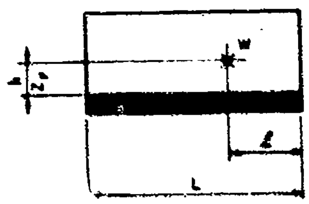




PARAMETERS



PLAN



ELEVATION

$\frac{L}{L_F} = 10.0$

$\frac{\ell}{L} = 0.25$

FIGURE A8

3

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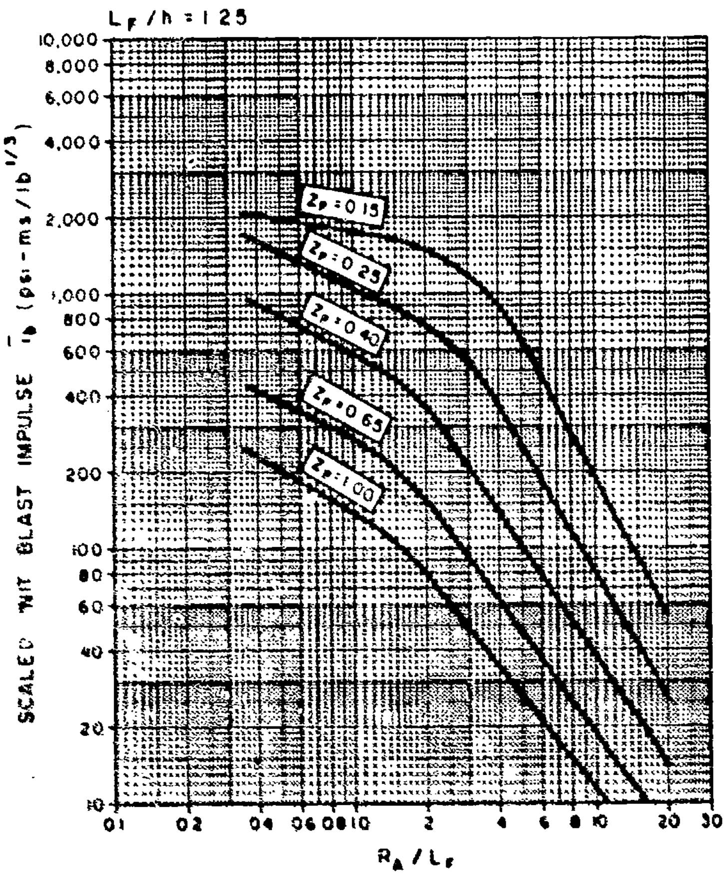
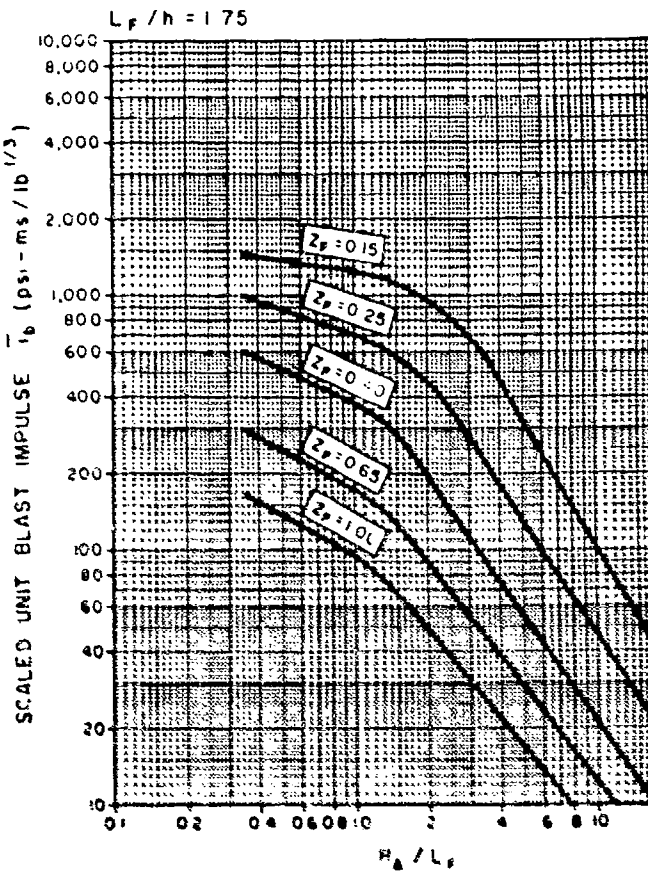
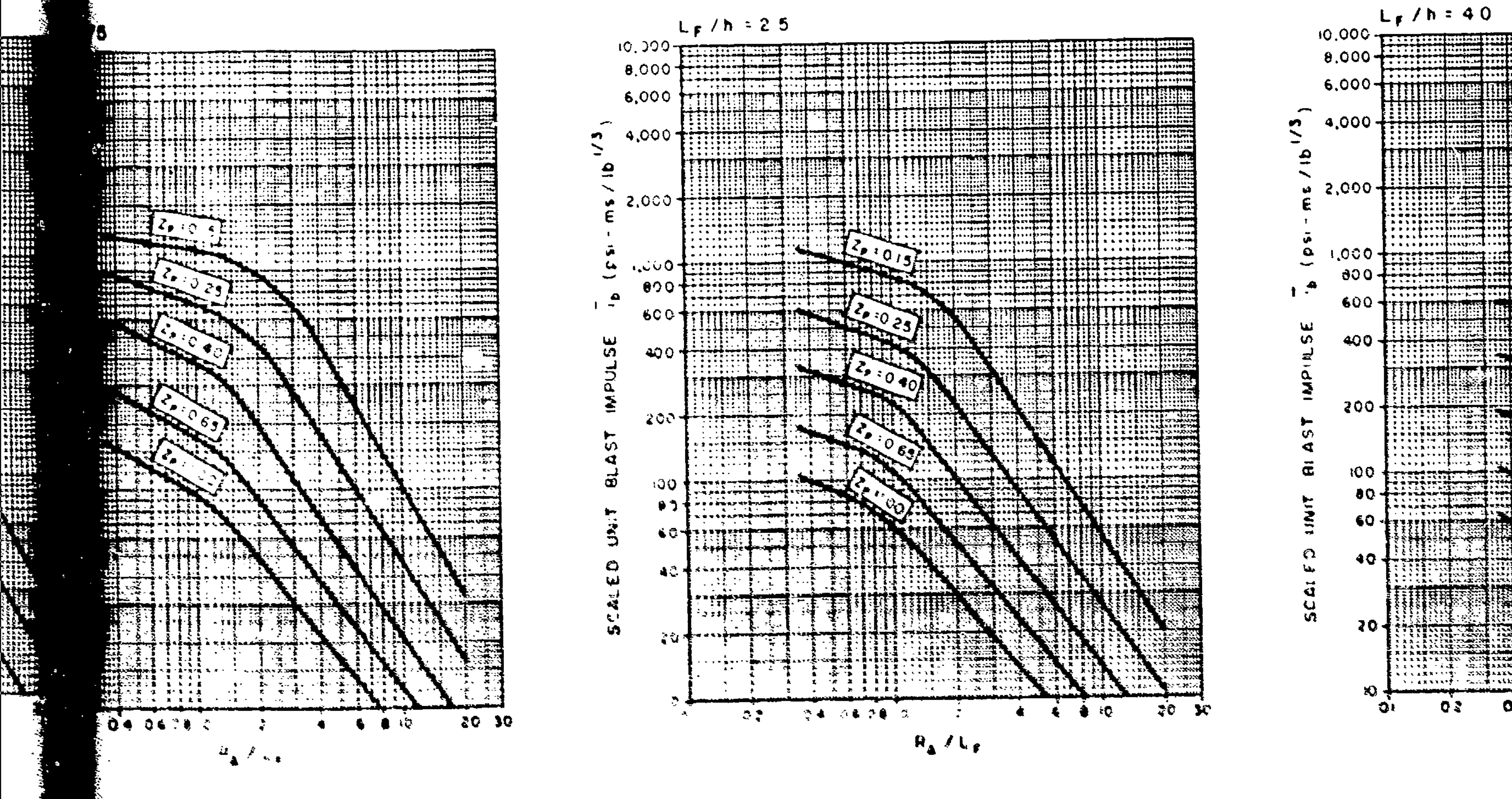


Lf /h = 1 25
SCALED UNIT BLAST IMPULSE ib (psi-ms/lb 1/3)
R_A / L_F
Zp = 0 15
Zp = 0 25
Zp = 0 40
Zp = 0 65
Zp = 1 00

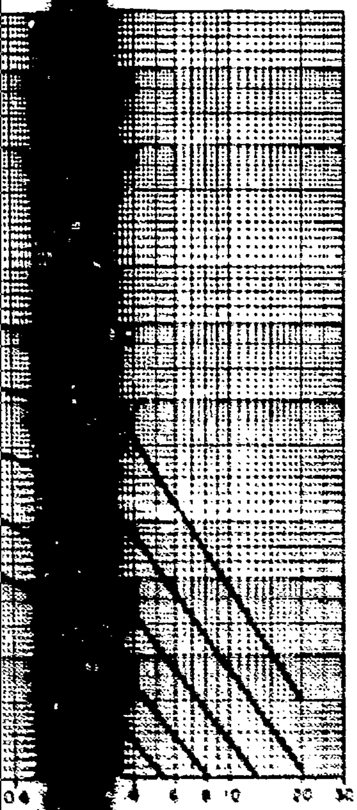


Lf /h = 1 75
SCALED UNIT BLAST IMPULSE ib (psi-ms/lb 1/3)
R_A / L_F
Zp = 0 15
Zp = 0 25
Zp = 0 65

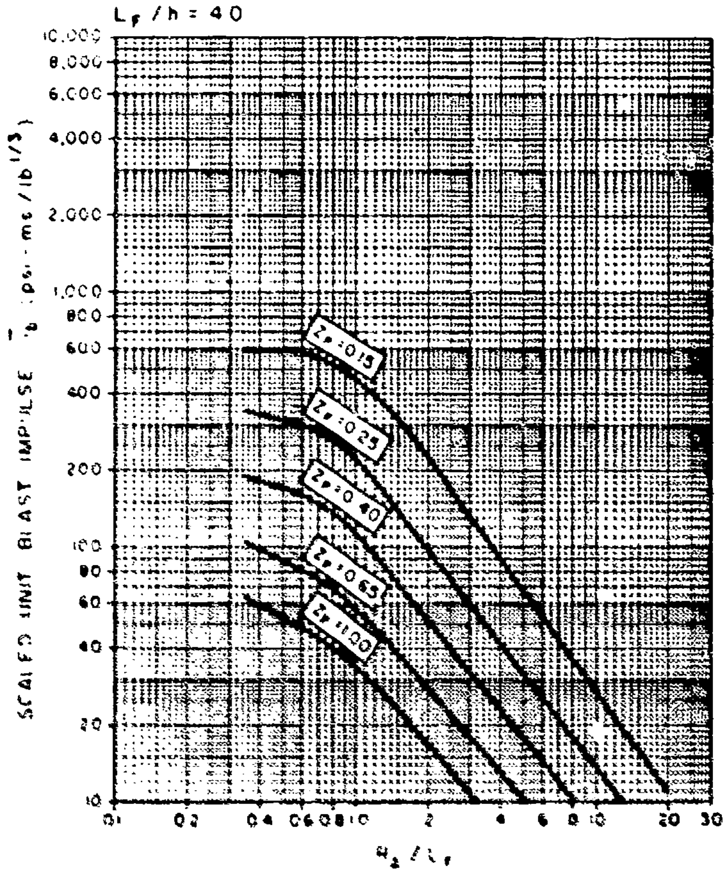
S



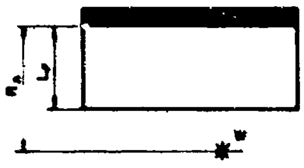
Scaled average unit blast impulse (L/L_F=1.0, Z/L=0.50)



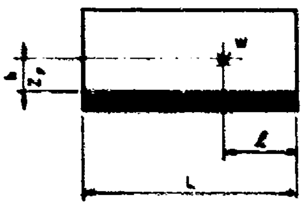
L=0.50)



PARAMETERS



PLAN



ELEVATION

$\frac{L}{L_f} = 1.0$

$\frac{\ell}{L} = 0.5$

FIGURE A10

3

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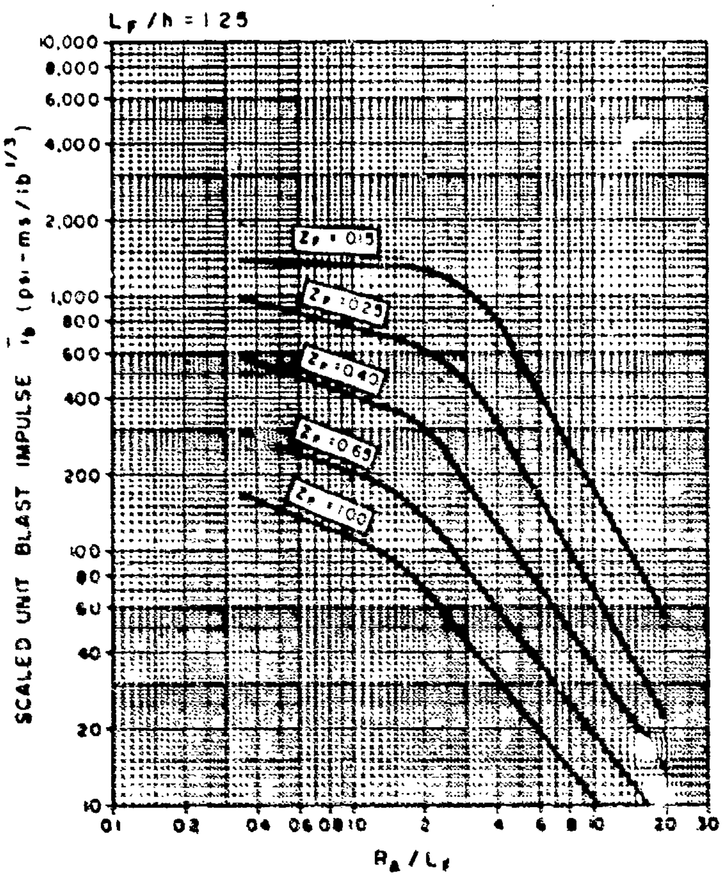
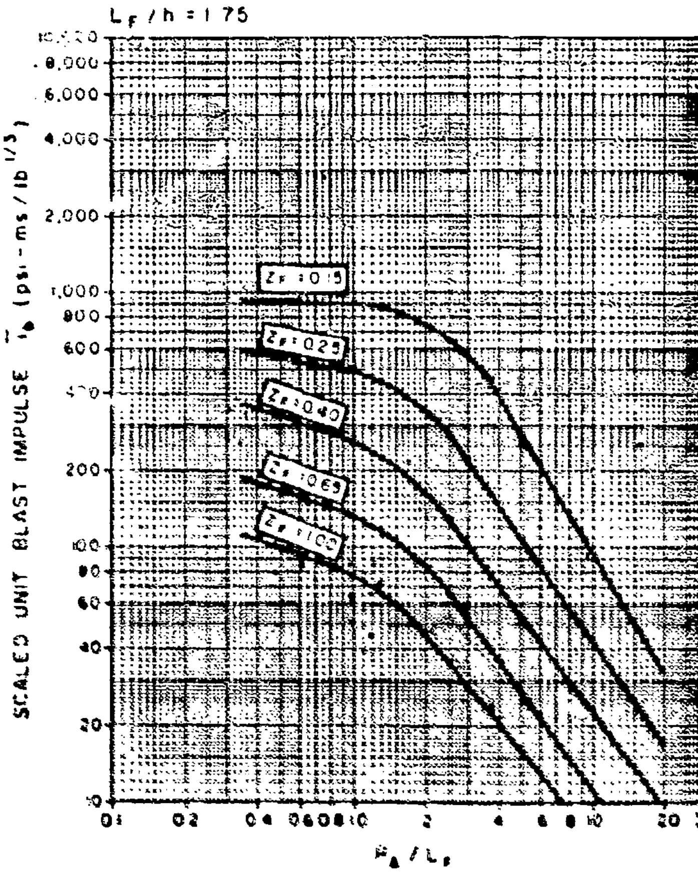
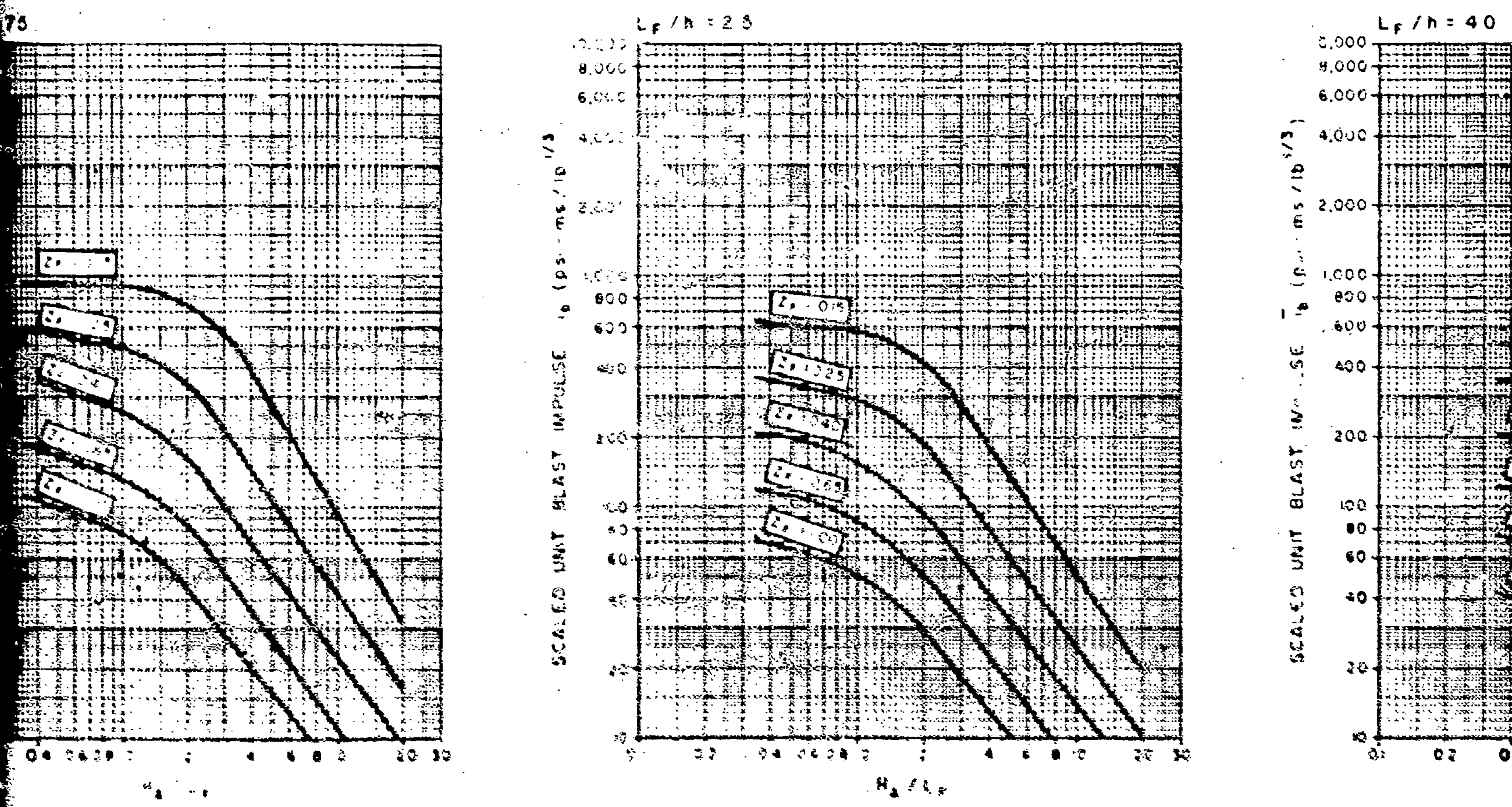


L_F / h = 1.25
SCALED UNIT BLAST IMPULSE i_b (psi-ms/lb^1/3)
Z_F = 0.15
Z_F = 0.25
Z_F = 0.40
Z_F = 0.65
Z_F = 1.00
R_A / L_F

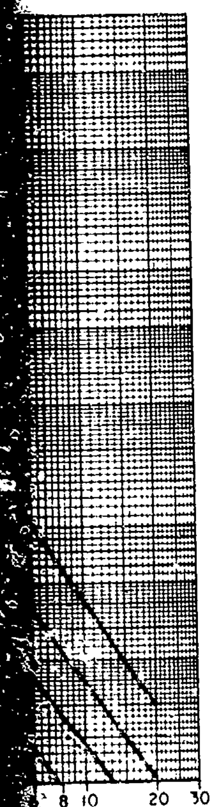


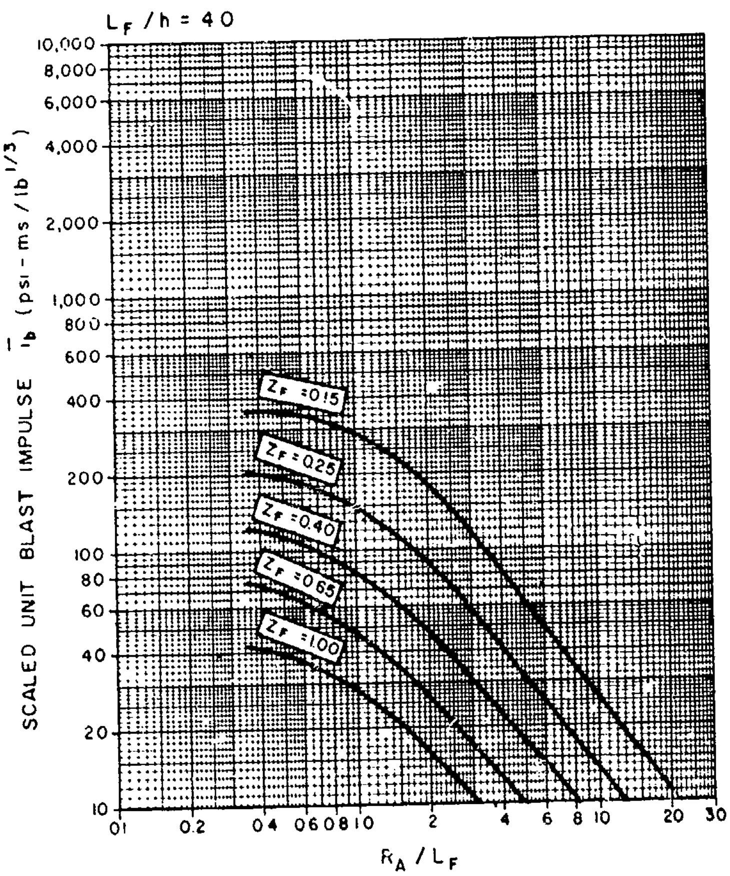
L_F / h = 1.75
SCALED UNIT BLAST IMPULSE i_b (psi-ms/lb^1/3)
Z_F = 0.15
Z_F = 0.25
Z_F = 0.40
Z_F = 0.65
Z_F = 1.00
R_A / L_F

Scaled a



Scaled average unit blast impulse (L/Lf=3.0, Z/L=0.50)





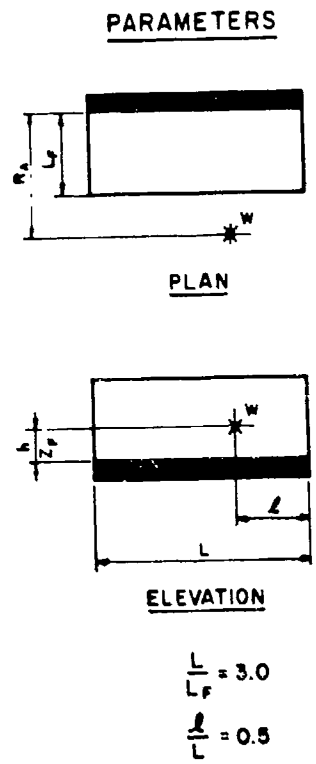


FIGURE A11

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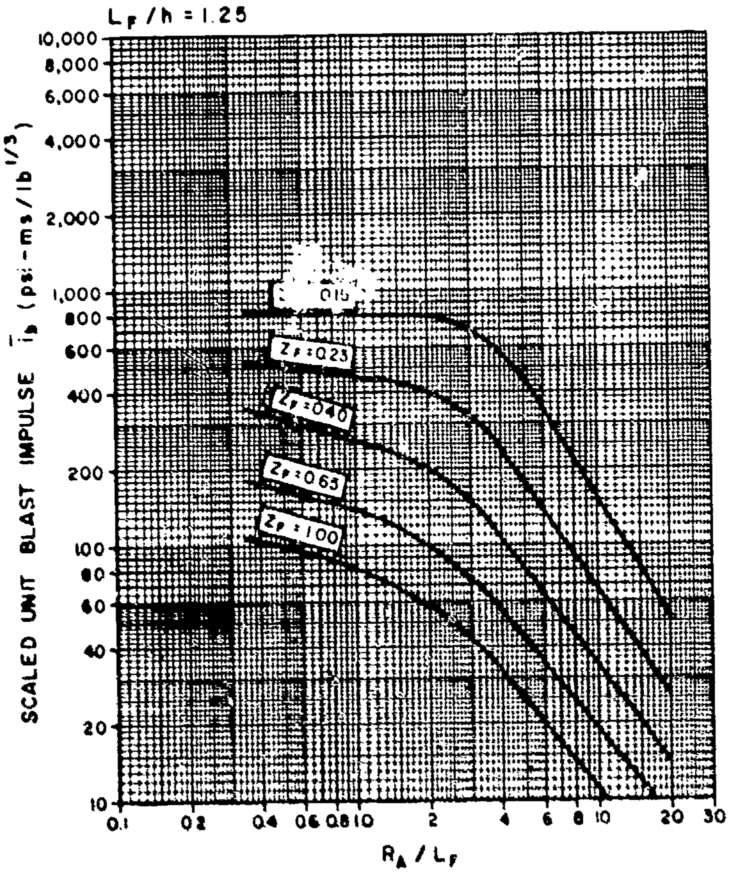
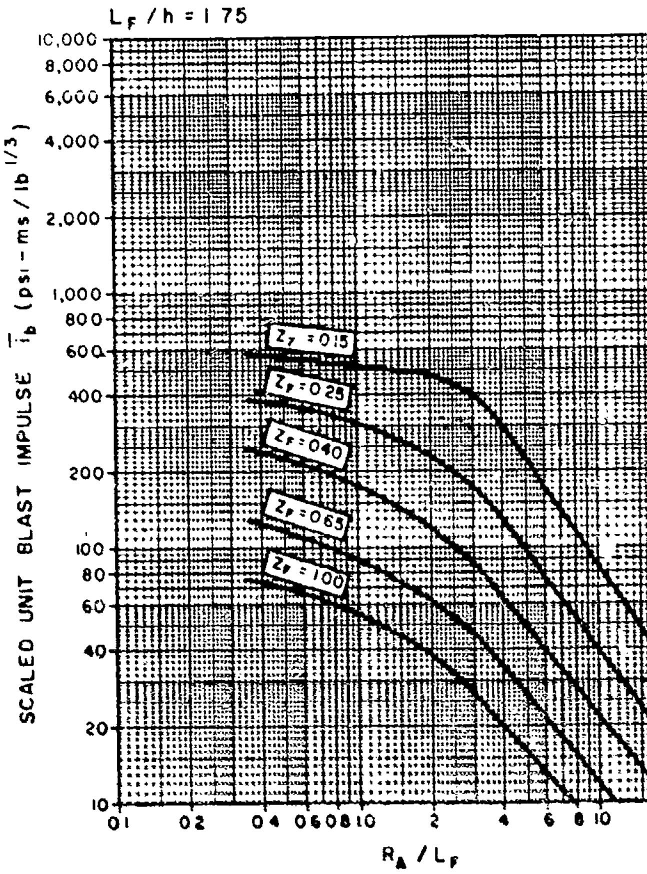
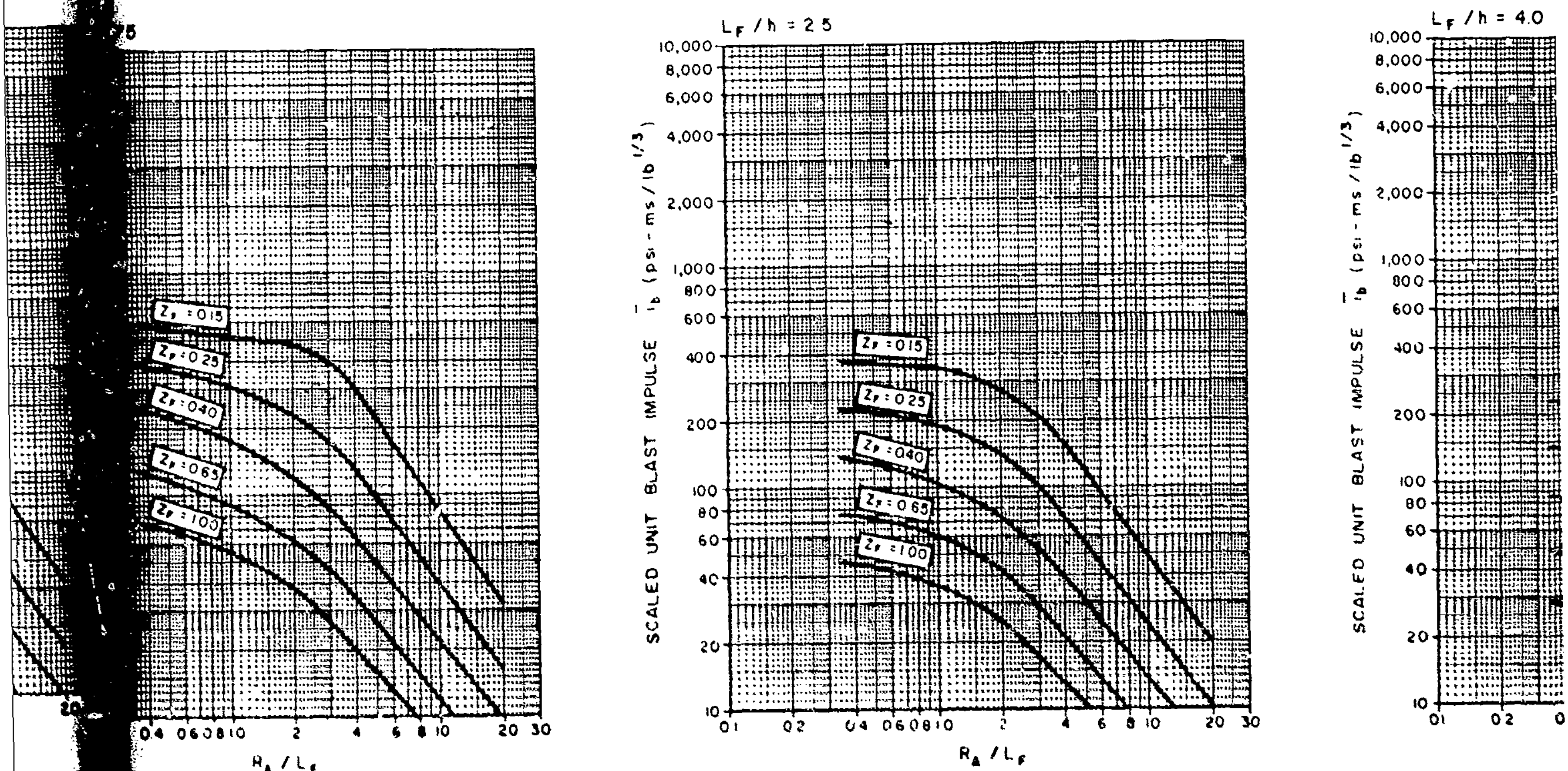


LF / h = 1.25
SCALED UNIT BLAST IMPULSE ib (psi-ms / lb 1/3)
RA / LF
ZF = 0.25
ZF = 0.40
ZF = 0.65
ZF = 1.00



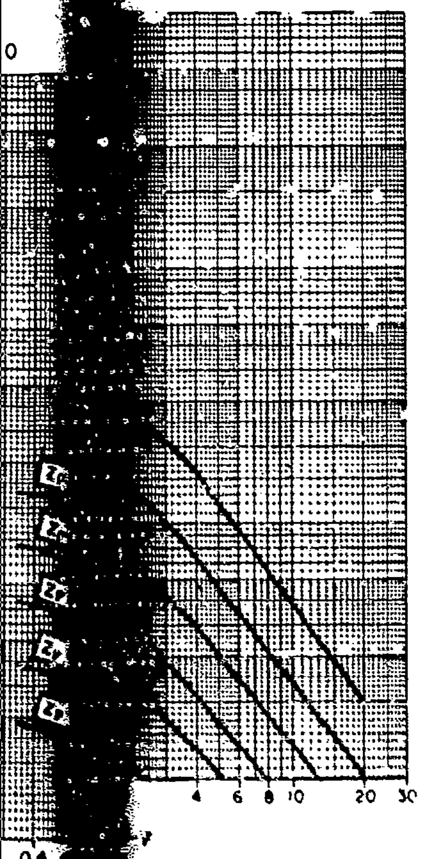
LF / h = 1.75
SCALED UNIT BLAST IMPULSE ib (psi-ms / lb 1/3)
RA / LF
ZF = 0.15
ZF = 0.25
ZF = 0.40
ZF = 0.65
ZF = 1.00

Sca

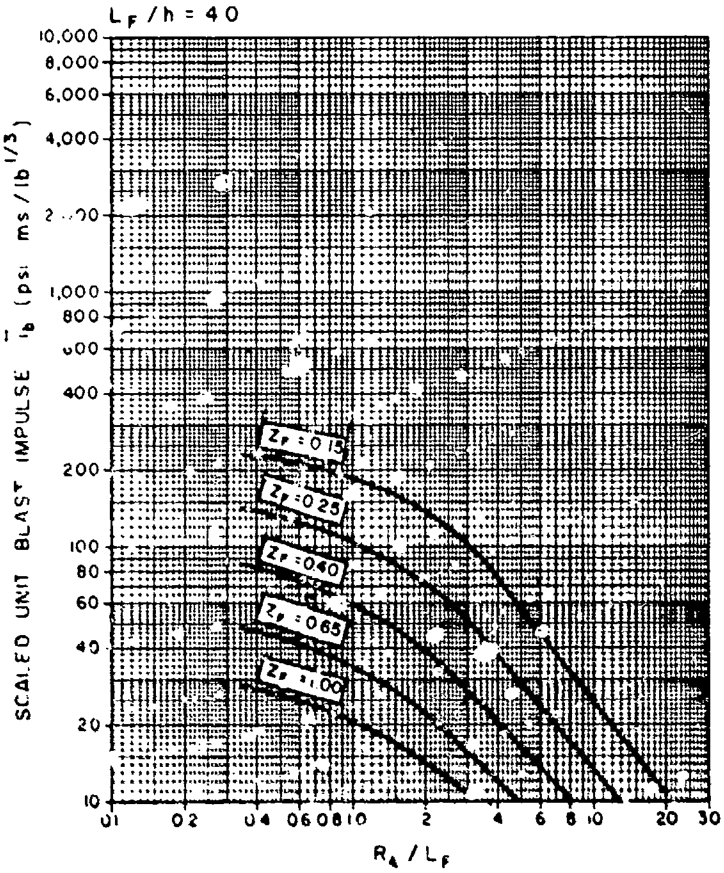


Scaled

Scaled average unit blast impulse (L/LF=6.5, Z/L=0.50)



/L=0.50)



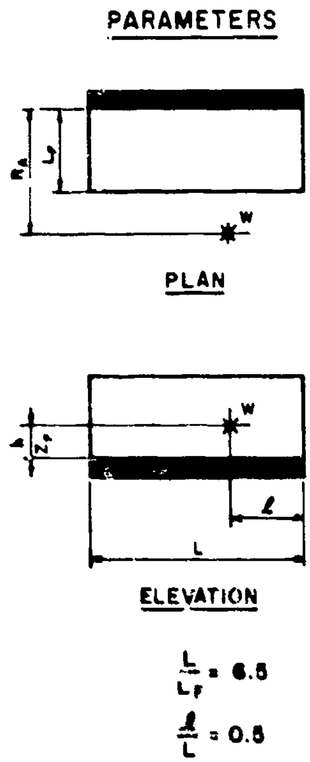


FIGURE A.12

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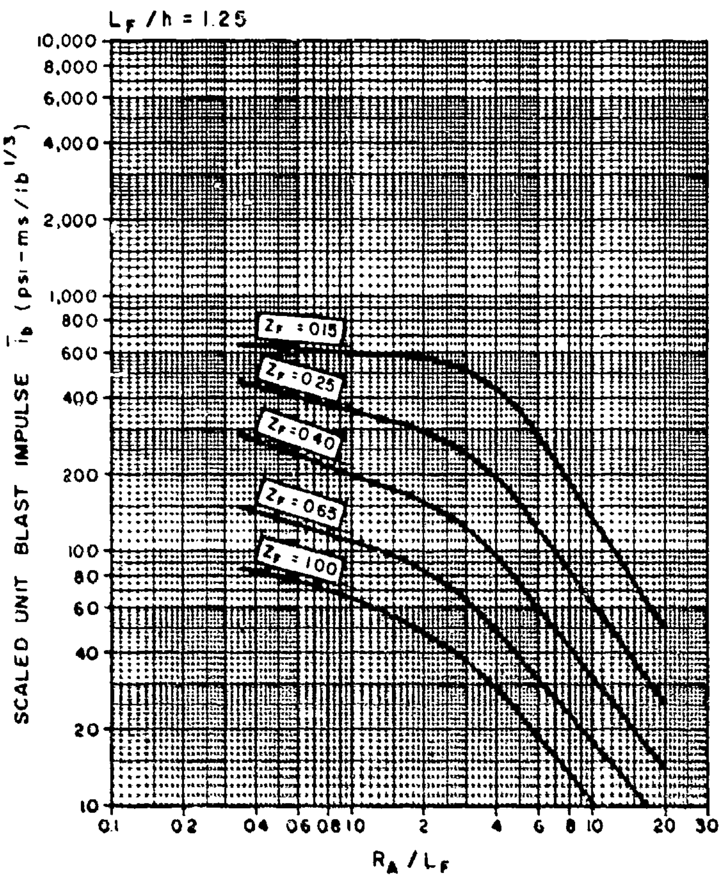
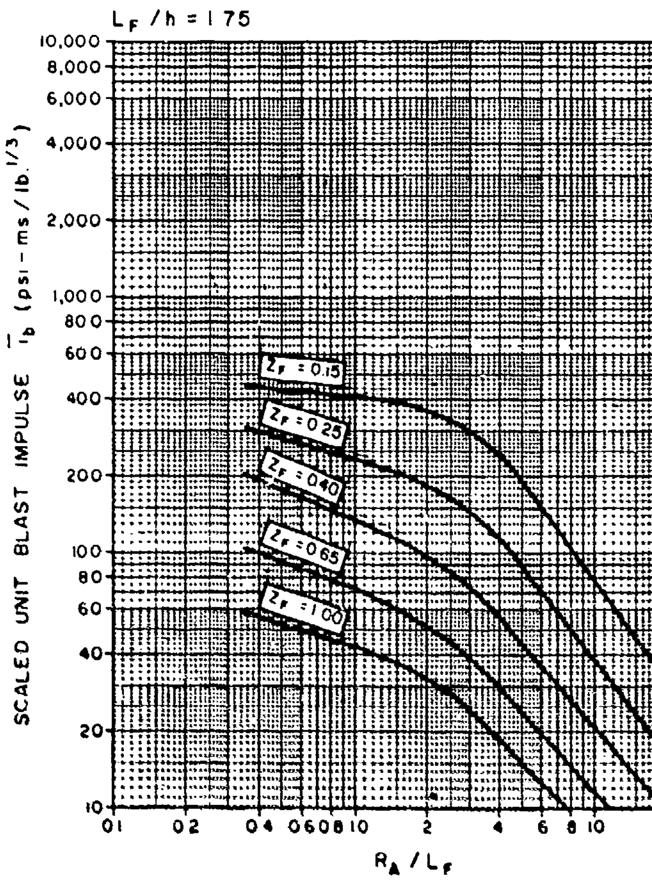


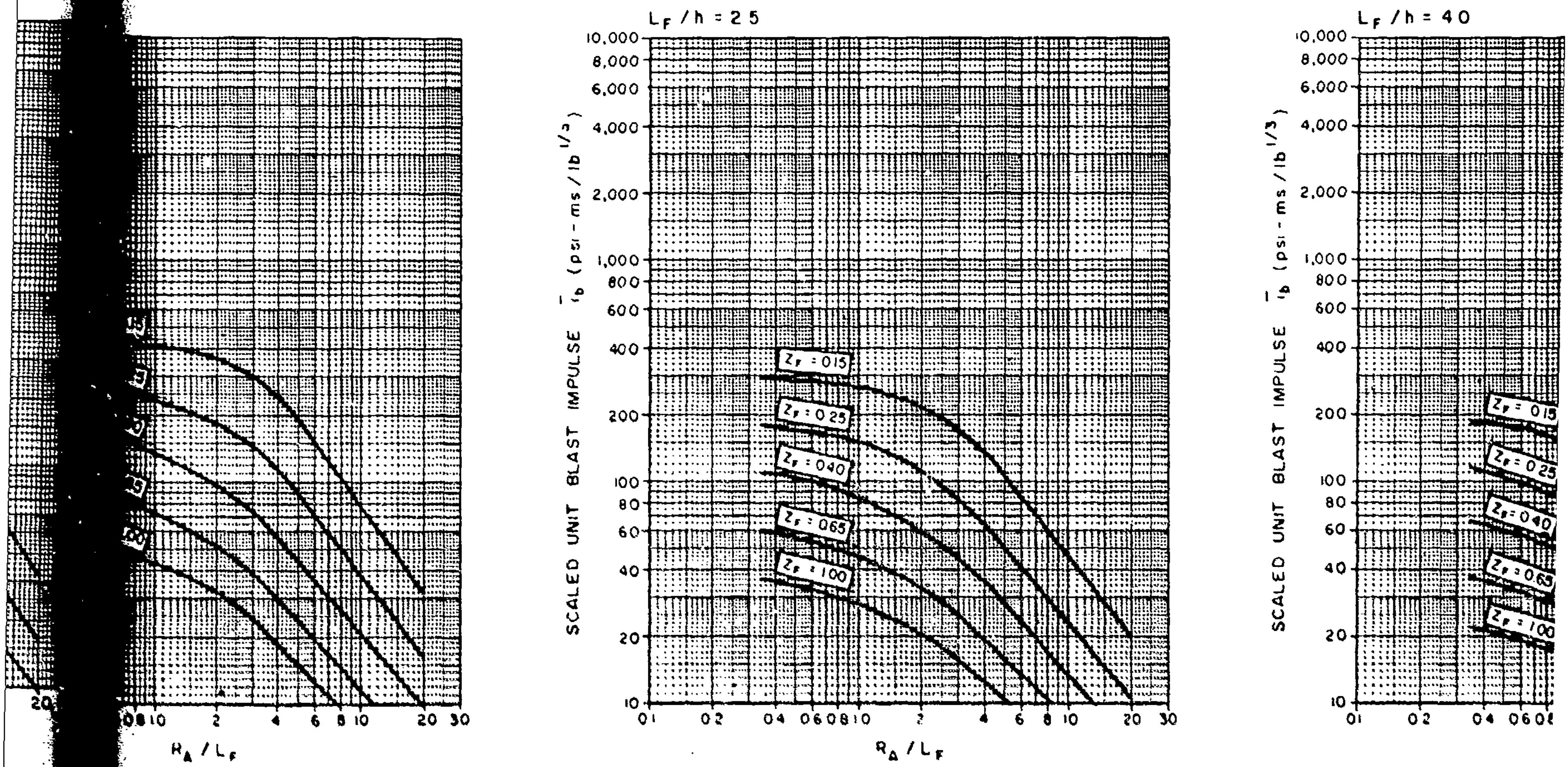
$L_F / h = 1.25$
SCALED UNIT BLAST IMPULSE $\bar{i}_b$ (psi-ms/lb$^{1/3}$)
$Z_F = 0.15$
$Z_F = 0.25$
$Z_F = 0.40$
$Z_F = 0.65$
$Z_F = 1.00$
R_A / L_F



$L_F / h = 1.75$
SCALED UNIT BLAST IMPULSE $\bar{i}_b$ (psi-ms/lb$^{1/3}$)
$Z_F = 0.15$
$Z_F = 0.25$
$Z_F = 0.40$
$Z_F = 0.65$
$Z_F = 1.00$
R_A / L_F

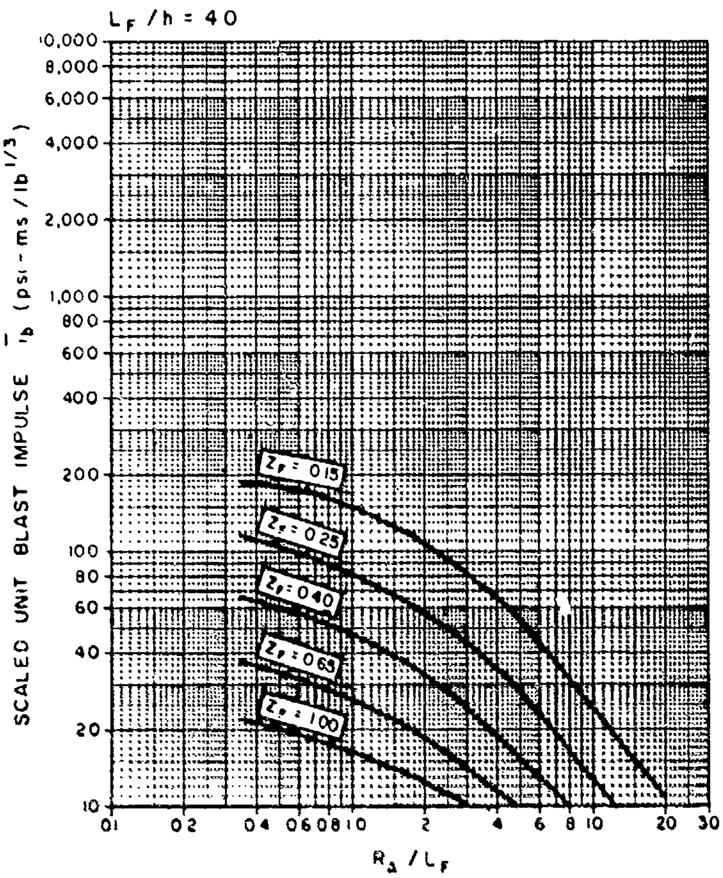
Scalec

ed a



Scaled average unit blast impulse (L/L_F=10.0, Z/L=0.50)

2


$L_F / h = 40$
SCALED UNIT BLAST IMPULSE $\bar{i}_b$ (psi-ms/lb$^{1/3}$)
10,000
8,000
6,000
4,000
2,000
1,000
800
600
400
200
100
80
60
40
20
10
$Z_F = 0.15$
$Z_F = 0.25$
$Z_F = 0.40$
$Z_F = 0.63$
$Z_F = 1.00$
0.1
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
20
30
R_A / L_F

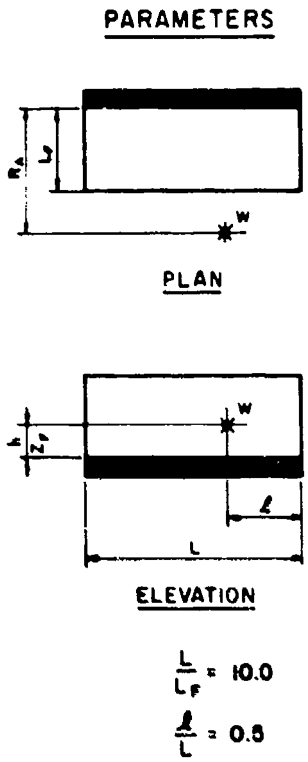

PARAMETERS
R_A
L_F
W
PLAN
W
h
Z_F
ℓ
L
ELEVATION
$\frac{L}{L_F} = 10.0$
$\frac{\ell}{L} = 0.5$

FIGURE A13

A.2 Computation Procedure and Sample Problem

The computation of the average impulse load proceeds as follows:

Problem: Determine the average impulse load on the foundation slab of a cantilever wall barrier.

Procedure:

Step 1. Determine the following:

a. Charge weight

b. Structure dimensions, L, L_F

c. Charge location parameters R_A, h, l

Step 2. Apply a 20% safety factor to the charge weight.

Step 3. Calculate the chart parameters, l/L, L/L_F, R_A/L_F, L_F/h and the scaled distance Z_F.

Note: Use of the average impulse charts may require interpolation in many cases. Interpolation may be achieved by inspection for the scaled distance, Z_F, and by a graphical procedure for the chart parameters L_F/h, L/L_F and l/L using 2 cycle by 2 cycle logarithmic graph paper. The following procedure will illustrate the interpolation of all three chart parameters.

Step 4. Determine and tabulate the values of the average scaled impulse $\bar{i}_b$ from the impulse charts for the required R_A/L_F and Z_F and the following variables:

L_F/h = 1.25, 1.75, 2.5 and 4.0

L/L_F = 1.00, 3.00, 6.50 and 10.0

l/L = 0.10, 0.25 and 0.50

FOR REQUIRED R_A/L_F AND Z_F

l/L	0.10				0.25				0.50			
L/L_F \ L_F/h	1.00	3.00	6.50	10.0	1.00	3.00	6.50	10.0	1.00	3.00	6.50	10.0
1.25 1.75 2.50 4.00												
Figure	A.2	A.3	A.4	A.5	A.6	A.7	A.8	A.9	A.10	A.11	A.12	A.13

Step 5 a. Prepare three 2-cycle log-log charts with L_F/h as the lower abscissa, L/L_F as the upper abscissa, and $\bar{i}_b$ as the ordinate (one chart for each of the l/L ratios). On each chart for constant l/L and Z_F, plot $\bar{i}_b$ versus L_F/h for all L/L_F values.

b. Using chart for $l/L = 0.10$, read values of $\bar{i}_b$ versus L/L_F for required L_F/h. Tabulate results.

FOR $l/L = 0.10$ AND REQUIRED L_F/h

L/L_F	$\bar{i}_b$
0.10 0.25 0.50 0.75	

c. Repeat Step 5b for charts l/L = 0.25 and 0.50. Tabulate results.

d. On each l/L chart, plot $\bar{i}_b$ versus L/L_F from Steps 5b and 5c.

e. On each l/L chart, read $\bar{i}_b$ for required L/L_F ratio. Tabulate results.

FOR CALCULATED L/L_F

l/L	$\bar{i}_b$
0.15	
0.25	
0.50	
0.75	

f. On a fourth chart, plot $\bar{i}_b$ from Step 5e versus l/L.

Step 6. For required l/L ratio, read $\bar{i}_b$ from chart of Step 5f. Calculate the unit blast impulse load on the foundation:

$$i_b = \bar{i}_b(W)^{1/3}$$

Example A.1: Computation of Average Impulse Load on Foundation Slab of Cantilever Wall Barrier.

Required: Average impulse load on the foundation slab of a cantilever wall barrier.

Step 1. Given:

a. Charge weight: 833.3 lbs

b. Structure dimensions (Figure A.14):

L = 48 ft $\quad$ L_F = 8.5 ft

c. Charge location parameters (Figure A.14):

R_A = 20 ft, h = 3.5 ft, l = 20 ft

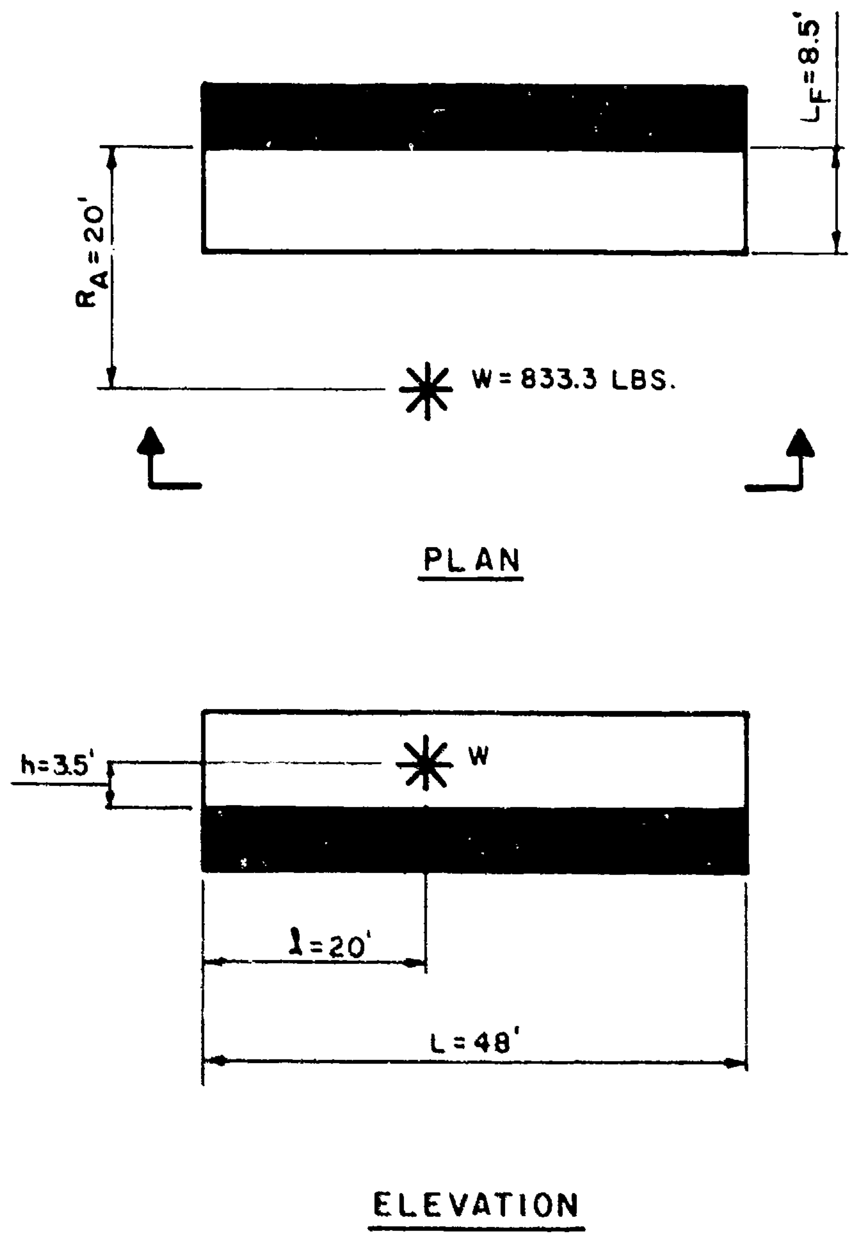


Figure A.14 Example A.1: Dimensions of structure and charge location parameters.

Step 2. $W = 1.20(833.3) = 1{,}000$ lbs

Step 3. Calculate the chart parameters:

$l/L = 0.42$, $L/L_F = 5.65$, $L_F/h = 2.43$

$R_A/L_F = 2.35$

$Z_F = h/W^{1/3} = 3.5/(1{,}000)^{1/3} = 0.35\ \text{ft/lb}^{1/3}$

Interpolation is required for Z_F, L_F/h, L/L_F and l/L.

Step 4. Determine and tabulate the values of $\bar{i}_b$ from Figures A.2 through A.13 for $R_A/L_F = 2.35$, $Z_F = 0.35$ (interpolate by inspection) and for values given for l/L, L/L_F and L_F/h.

The tabulation of the impulses is provided in Table A.1.

Step 5. a. Plot $\bar{i}_b$ versus L_F/h for the values of L/L_F and constant l/L (Figure A.15).

b. Determine $\bar{i}_b$ for $L_F/h = 2.43$, $l/L = 0.10$ and various L/L_F ratios by entering Figure A.15(a) with $L_F/h = 2.43$.

L/L_F	$\bar{i}_b$
1.0	105
3.0	92
6.5	66
10.0	55

c. Repeat above step for $l/L = 0.25$ and 0.50 by entering (b) and (c) of Figure A.15 with $L_F/h = 2.43$ (tabulation of results not shown).

d. On each l/L chart, plot $\bar{i}_b$ (Steps 5b and 5c) versus L/L_F [upper abscissa of (a) through (c) of Figure A.15].

TABLE A.1

TABULATION OF $\bar{T}_b$ FOR $R_A/L_F = 2.35$, $Z_F = 0.35$ AND VARIOUS ℓ/L, L/L_F AND L_F/h RATIOS

ℓ/L	0.10				0.25				0.50			
L/L_F \ L_F/h	1.00	3.00	6.50	10.0	1.00	3.00	6.50	10.0	1.00	3.00	6.50	10.0
1.25	360	270	185	145	370	300	210	160	400	320	215	173
1.75	195	155	110	90	205	165	125	105	210	175	125	105
2.50	100	90	63	53	103	92	70	60	105	95	80	66
4.00	48	45	34	27	50	45	38	34	51	47	40	35
Figure	A.2	A.3	A.4	A.5	A.6	A.7	A.8	A.9	A.10	A.11	A.12	A.13

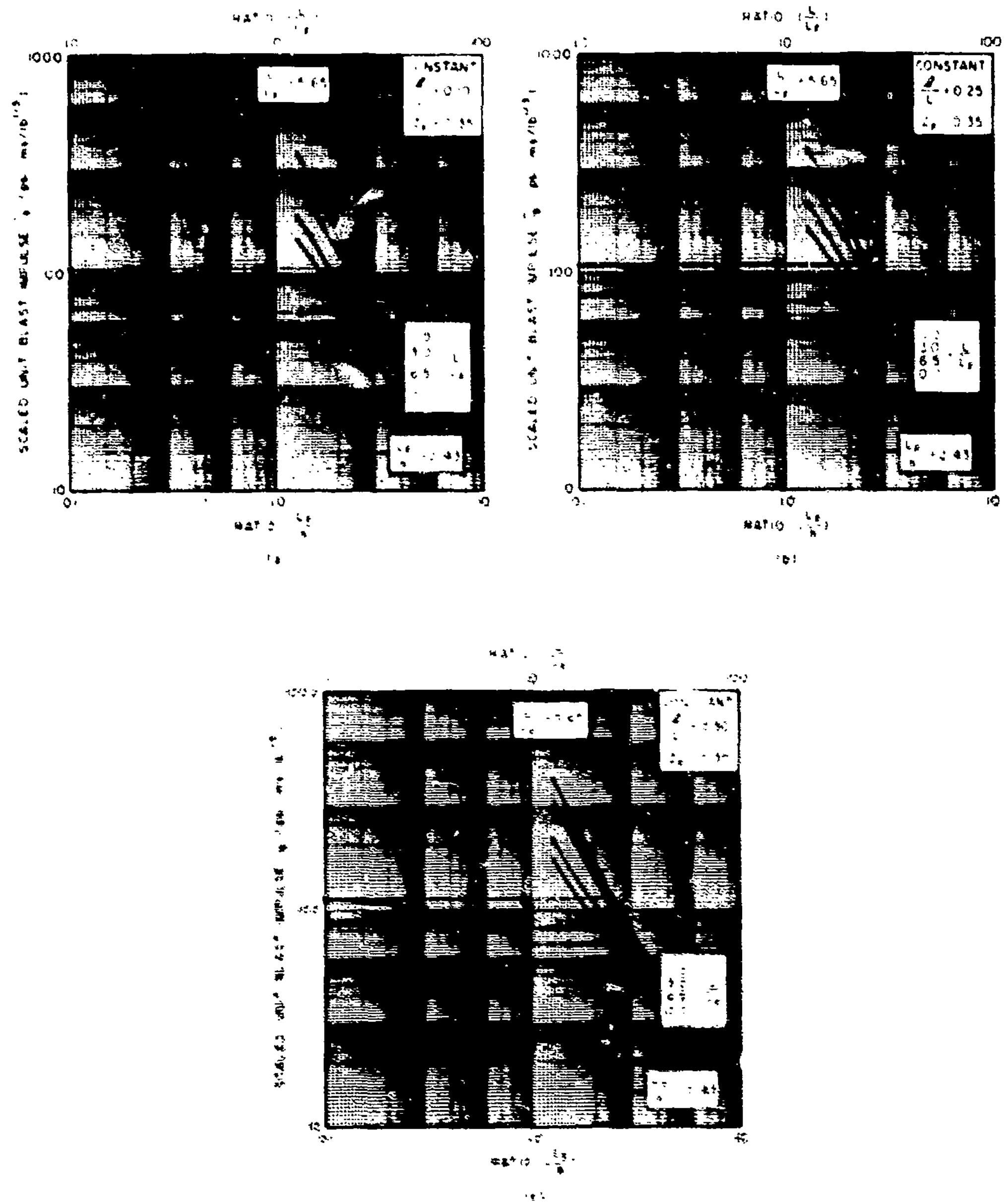


Figure A.15 Example A.1: Interpolation of scaled impulse for L_F/h and L/L_F ratios.

e. Determine $\bar{i}_b$ for $L/L_F = 5.65$ on each l/L chart by entering (a) through (c) of Figure A.15 with $L/L_F = 5.65$ and reading curves plotted in Step 5d.

l/L	$\bar{i}_b$	Figure
0.10	70	A.15(a)
0.25	78	A.15(b)
0.50	86	A.15(c)

f. Plot $\bar{i}_b$ (Step 5e) versus l/L (Figure A.16).

Step 6. For $l/L = 0.42$ read $\bar{i}_b = 84$ ps-ms/lb$^{1/3}$ on Figure A.16. Compute i_b:

$$i_b = \bar{i}_b W^{1/3} = 84(1,000)^{1/3} = 840 \text{ psi-ms}$$

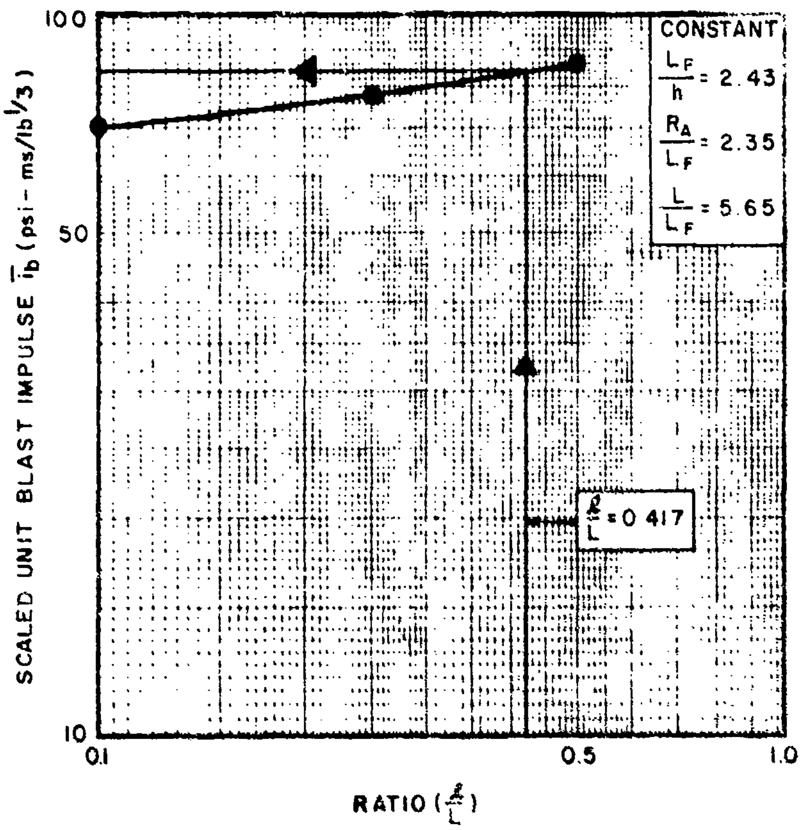


Figure A.16 Example A.1: Interpolation of scaled impulse for l/L ratios.

APPENDIX B

PROCEDURE FOR CALCULATING ARRIVAL TIME AND DURATION OF BLAST LOADS ON THE STRUCTURE

B.1 Computation Procedure and Sample Problem

This appendix contains the procedure (described in Section 3.3) utilized by the computer program to calculate the arrival time and duration of the blast loading on the structure. The procedure is based on the methods and empirical data presented in Chapter 4 of Reference 1.

The computation proceeds as follows:

Problem: Determine the arrival and duration times of blast loads on structure.

Procedure:

Step 1. Determine the following:

a. Charge weight

b. Structure dimensions

c. Distance from charge to back wall, R_A

d. Height of charge above foundation slab, h

Step 2. Apply a 20 percent safety factor to the charge weight.

Step 3. Determine the minimum scaled distance from the charge to each loaded surface. With these values, enter Figure B.1 and read off the curve labeled "$t_A/W^{1/3}$", the scaled times of arrival of the blast wave on each surface.

Step 4. Determine the scaled distances from the charge to the four corners of each loaded surface. Enter Figure B.1 and read off the curve labeled "$t_A/W^{1/3}$", the scaled times of arrival of the blast wave at these points. At the same time, read off the curve labeled "$t_o/W^{1/3}$", the scaled positive phase durations at these points.

Step 5. Calculate the average time for the wave to fully engulf each surface and the average of the positive phase duration times at the farthest points on each surface.

$$[(t_A)]_{avg} = \frac{(t_A)_{F1} + (t_A)_{F2} + (t_A)_{F3} + (t_A)_{F4}}{4}$$

$$[(t_o)]_{avg} = \frac{(t_o)_{F1} + (t_o)_{F2} + (t_o)_{F3} + (t_o)_{F4}}{4}$$

where:

$(t_A)_F$ = arrival time at one corner of surface

$(t_o)_F$ = positive phase duration at one corner

$(t_A)_{avg}$ = average time for wave to fully engulf surface

$(t_o)_{avg}$ = average of positive phase durations at the farthest points

Step 6. Calculate the duration of the loading on each surface using the following equation:

$$t_o = [(t_A)]_{avg} - (t_A)_A + [(t_o)]_{avg}$$

where:

$(t_A)_A$ = arrival time of the blast wave at the point on the element nearest to the explosion, defined by the normal distance

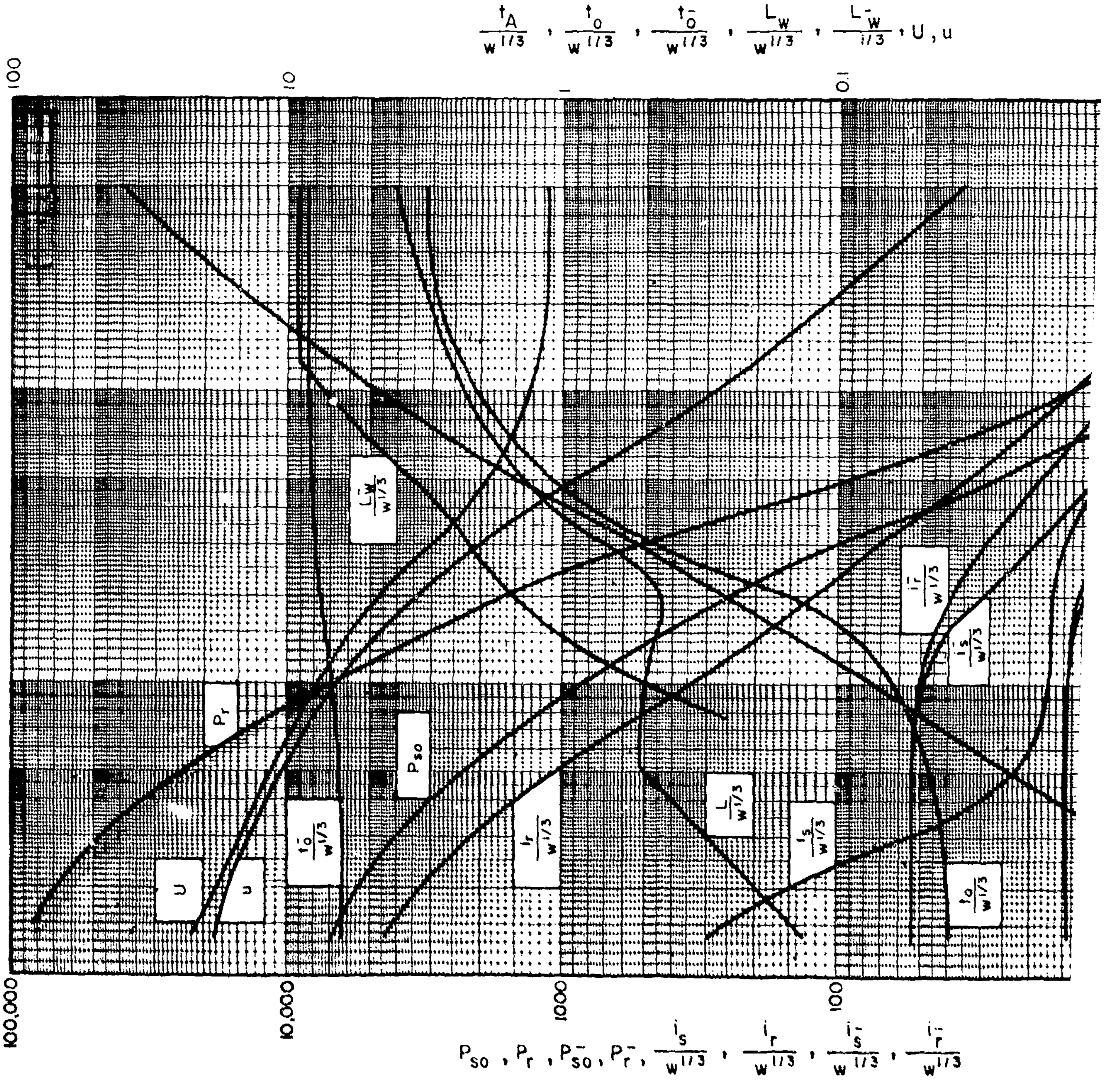
Example B.1: Cantilever wall barrier with foundation.

Required: Arrival time and duration of blast on cantilever wall and foundation.

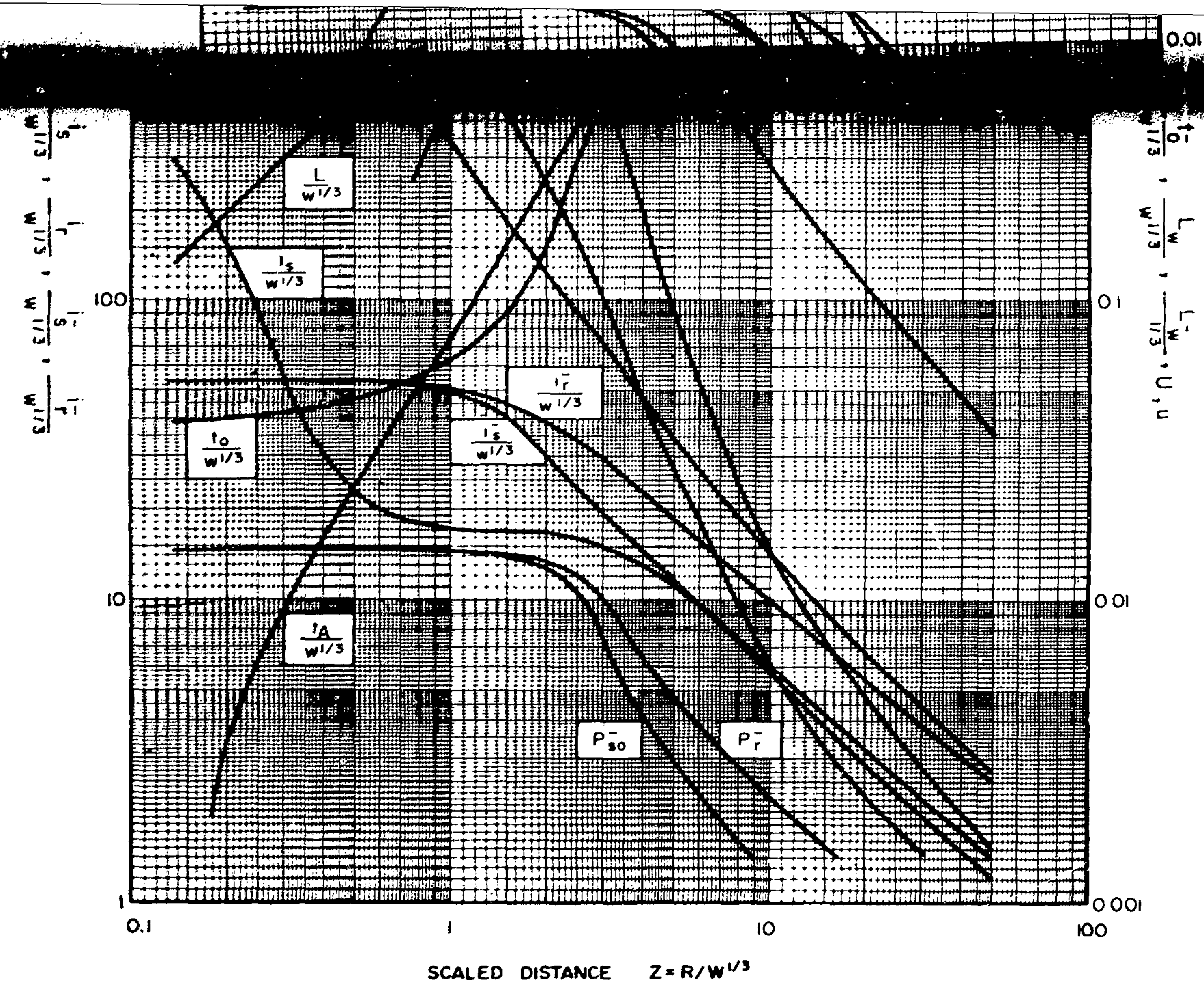
Step 1. Given:

a. Charge weight: 833.3 lbs

b. Configuration of structure (Figure B.2)



tA/W1/3 , to/W1/3 , to-/W1/3 , Lw/W1/3 , Lw-/W1/3 , U , u
100
10
1
0.1
100,000
10,000
1000
100
Pso , Pr , Pso- , Pr- , is/W1/3 , ir/W1/3 , is-/W1/3 , ir-/W1/3



P_{so} = Peak Positive Incident Pressure, psi
P_{so}^- = Peak Negative Incident Pressure, psi
P_r = Peak Positive Normal Reflected Pressure, psi
P_r^- = Peak Negative Normal Reflected Pressure, psi
$i_s/W^{1/3}$ = Scaled Unit Positive Incident Impulse, psi-ms/lb$^{1/3}$
$i_s^-/W^{1/3}$ = Scaled Unit Negative Incident Impulse, psi-ms/lb$^{1/3}$
$i_r/W^{1/3}$ = Scaled Unit Positive Normal Reflected Impulse, psi-ms/lb$^{1/3}$
$i_r^-/W^{1/3}$ = Scaled Unit Negative Normal Reflected Impulse, psi-ms/lb$^{1/3}$
$t_A/W^{1/3}$ = Scaled Time of Arrival of Blast Wave, ms/lb$^{1/3}$

$t_o/W^{1/3}$ = Scaled Positive Duration of Positive Phase, ms/lb$^{1/3}$
$t_o^-/W^{1/3}$ = Scaled Negative Duration of Positive Phase, ms/lb$^{1/3}$
$L_w/W^{1/3}$ = Scaled Wave Length of Positive Phase, ft/lb$^{1/3}$
$L_w^-/W^{1/3}$ = Scaled Wave Length of Negative Phase, ft/lb$^{1/3}$
U = Shock Front Velocity, ft/ms
u = Particle Velocity, ft/ms
W = Charge Weight, lbs
R = Radial Distance from Charge, ft
Z = Scaled Distance, ft/lb$^{1/3}$

Figure B.1 Shock wave parameters for spherical TNT explosion in free air at sea level

2

c. $R_A = 12$ ft

d. $h = 4$ ft

<u>Step 2</u>. $W = 1.20(833.3) = 1{,}000$ lbs

<u>Step 3</u>. Determine the minimum scaled distance from the charge to each loaded surface.

$W^{1/3} = 10\ \text{lb}^{1/3}$

Minimum scaled distance to wall:

$$Z_A = 12/10\ \text{ft(lb)}^{1/3} = 1.2\ \text{ft(lb)}^{1/3}$$

From Figure B.1, $(t_A/W^{1/3}) = .1\ \text{ms/(lb)}^{1/3}$

$(t_A)_A = (10)(.1) = 1.0$ ms

Minimum scaled distance to foundation:

$$Z_F = \sqrt{(4)^2 + (4)^2}\ /10 = .566\ \text{ft/(lb)}^{1/3}$$

From Figure B.1 $(t_A/W^{1/3}) = .0285\ \text{ms/(lb)}^{1/3}$

$(t_A)_A = 10(.0285) = .285$ ms

<u>Step 4</u>. Determine Z to the four corners of each surface.

Wall:

$$Z_1 = \sqrt{(4)^2 + (8)^2 + (12)^2}\ /10$$
$$= 1.496\ \text{ft/(lb)}^{1/3}$$

$$Z_3 = \sqrt{(12)^2 + (8)^2 + (12)^2}\ /10$$
$$= 1.875\ \text{ft/(lb)}^{1/3}$$

From Figure B.1 read:

$(t_A/W^{1/3})_1 = .155\ \text{ms/(lb)}^{1/3}$

$(t_o/W^{1/3})_1 = .090\ \text{ms/(lb)}^{1/3}$

$(t_A/W^{1/3})_3 = .23 \text{ ms}/(\text{lb})^{1/3}$

$(t_o/W^{1/3})_3 = .13 \text{ ms}/(\text{lb})^{1/3}$

Foundation:

$Z_1 = Z_2 = 1.496 \text{ ft}/(\text{lb})^{1/3}$

$$Z_5 = Z_6 = \sqrt{(4)^2 + (4)^2 + (8)^2}\,/10$$

$$= .98 \text{ ft}/(\text{lb})^{1/3}$$

From Figure B.1 read:

$(t_A/W^{1/3})_1 = .155 \text{ ms}/(\text{lb})^{1/3}$

$(t_o/W^{1/3})_1 = .090 \text{ ms}/(\text{lb})^{1/3}$

$(t_A/W^{1/3})_5 = .073 \text{ ms}/(\text{lb})^{1/3}$

$(t_o/W^{1/3})_5 = .063 \text{ ms}/(\text{lb})^{1/3}$

Step 5. Calculate $(t_A)_{avg}$ and $(t_o)_{avg}$ for the wall and foundation.

Wall:

$(t_A)_1 = 1.5545 \text{ ms}$ $\qquad$ $(t_A)_3 = 2.3 \text{ ms}$

$$[(t_A)_w]_{avg} = \frac{2(1.55) + 2(2.3)}{4} = 1.925 \text{ ms}$$

$(t_o)_1 = .9 \text{ ms}$ $\qquad$ $(t_o)_3 = 2.3 \text{ ms}$

$$[(t_o)_w]_{avg} = \frac{2(.9) + 2(1.3)}{4} = 1.1 \text{ ms}$$

Foundation:

$(t_A)_1 = 1.55 \text{ ms}$ $\qquad$ $(t_A)_5 = .73 \text{ ms}$

$$[(t_A)_F]_{avg} = \frac{2(1.55) + 2(.73)}{4} = 1.14 \text{ ms}$$

$(t_o)_1 = .9 \text{ ms}$ $\qquad$ $(t_o)_5 = .63 \text{ ms}$

$$[(t_o)_F]_{avg} = \frac{2(.9) + 2(.63)}{4} = .765 \text{ ms}$$

Step 6. Calculate the durations (t_0) for the wall and foundation.

Wall:

$[(t_A)_w]_{avg} = 1.925$ ms $\quad (t_A)_A = 1.0$ ms

$[(t_o)_w]_{avg} = 1.1$ ms

$(t_o)_W = 1.925 - 1.0 + 1.1 = 2.025$ ms

Foundation:

$[(t_A)_F]_{avg} = 1.14$ ms $\quad (t_A)_A = .285$ ms

$[(t_o)_F]_{avg} = .765$ ms

$(t_o)_F = 1.14 - .285 + .765 = 1.62$ ms

Results:

Wall:

Arrival time	1.000 ms
Duration of Loading	2.025 ms

Foundation:

Arrival time	0.285 ms
Duration of Loading	1.620 ms

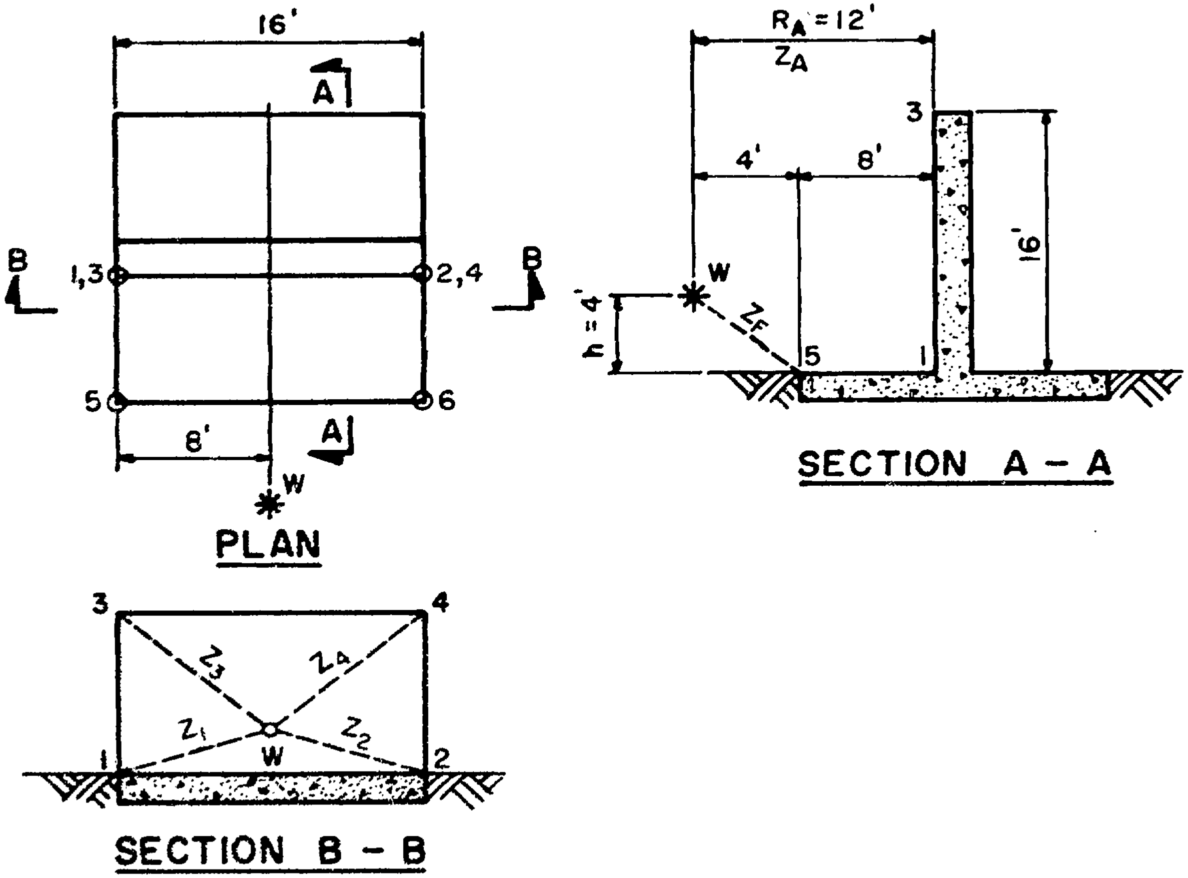


Figure B.2 Example B.1: Dimensions of structure and charge location parameters.

APPENDIX C

FOUNDATION DESIGN METHOD FOR PROTECTIVE STRUCTURES SUSCEPTIBLE TO OVERTURNING

C.1 General

This appendix presents the criteria and procedure for designing the foundations of protective structures susceptible to overturning. The design procedure is illustrated by two sample problems.

The design of protective structures susceptible to overturning and/or sliding motions proceeds in two stages. In the first stage, the walls of the structure are designed using the criteria, methods and data provided in Chapters 5 and 6 of Manual TM 5-1300 (Reference 1). The methods in the manual treat the design of each blast-resistant wall of the structure individually. The design is based on the assumption that the supports along the periphery of an element are completely fixed against translation and rotation and are capable of fully developing the strength of the element.

In the second stage, the structure foundation is designed for both the conventional working (dead and live) load and blast load conditions. Design procedures for the dead and live condition are well documented in textbooks on the design of reinforced concrete structures (see Reference 7).

Designing the foundation for the blast load condition requires performing an overturning analysis on the structure using the Overturning Analysis Computer Program presented in Section 5 of this report. The purpose of the analysis is to determine the peak response of the structure and the time history of the bearing pressures acting on the structure foundation. This data is used to determine the length of the foundation extension (see Figures C.1 and C.2) required to prevent the structure from overturning or sliding (large distances) and the thickness of concrete and area of flexural reinforcement required to resist the bearing pressures developed in the soil beneath the foundation.

C.2 Preliminary Tasks

C.2.1 Introduction

Two preliminary tasks must be accomplished before the overturning analysis of the structure is performed. These tasks are: (1) estimating an initial size of the foundation extension for use in the analysis and (2) determining, with the test data

available for the soil at the construction site, the soil properties to be used in the analysis.

Since some aspects of these tasks are rather complex, a detailed discussion of them is provided before the design method is presented. These tasks are included in the procedure for designing the foundation.

A discussion of the preliminary tasks is presented in the following sections.

C.2.2 Initial Estimate of Foundation Size

In order to perform an overturning analysis, the complete geometry of the structure must be supplied to the computer program. As described in Section 5 of this report, the information required consists of the configuration of the structure described in terms of the number and sizes (length, height, thickness) of each of the blast-resistant wall elements of the structure.

The sizes of the blast-resistant walls are determined using the criteria, methods and data of Reference 1. Initially, the size of the foundation is not known since the foundation design, to some extent depending upon the type of structure, is governed by the results of the overturning analysis. To proceed with the analysis, some reliable estimates of the foundation dimensions are required. To this end, initial estimates of the foundation dimensions are presented in the next several paragraphs. These estimates are based on the results of several actual design studies of protective structures susceptible to overturning.

Cantilever wall barriers, lacking massive sidewalls which help prevent the structure from overturning, depend entirely on the foundation extension and the soil beneath it to limit the motions of the structure. Consequently, a relatively large foundation extension is required. The initial foundation thickness to be used in the overturning analysis should be approximately 1.25 times the wall thickness and the initial extension length utilized should be approximately 45 percent of the height of the wall (see Figure C.1). Sloping the bottom face of the foundation as shown in Figure C.1 is permissible; but the angle between the bottom face and the horizontal should be limited to 5 degrees. Larger slopes will significantly decrease the moment arm of the resultant of the soil pressures about the center of gravity of the structure.

Generally, cantilever barrier foundations should be symmetric about the centerline of the wall unless building constraints dictate otherwise. If the analysis indicates that the

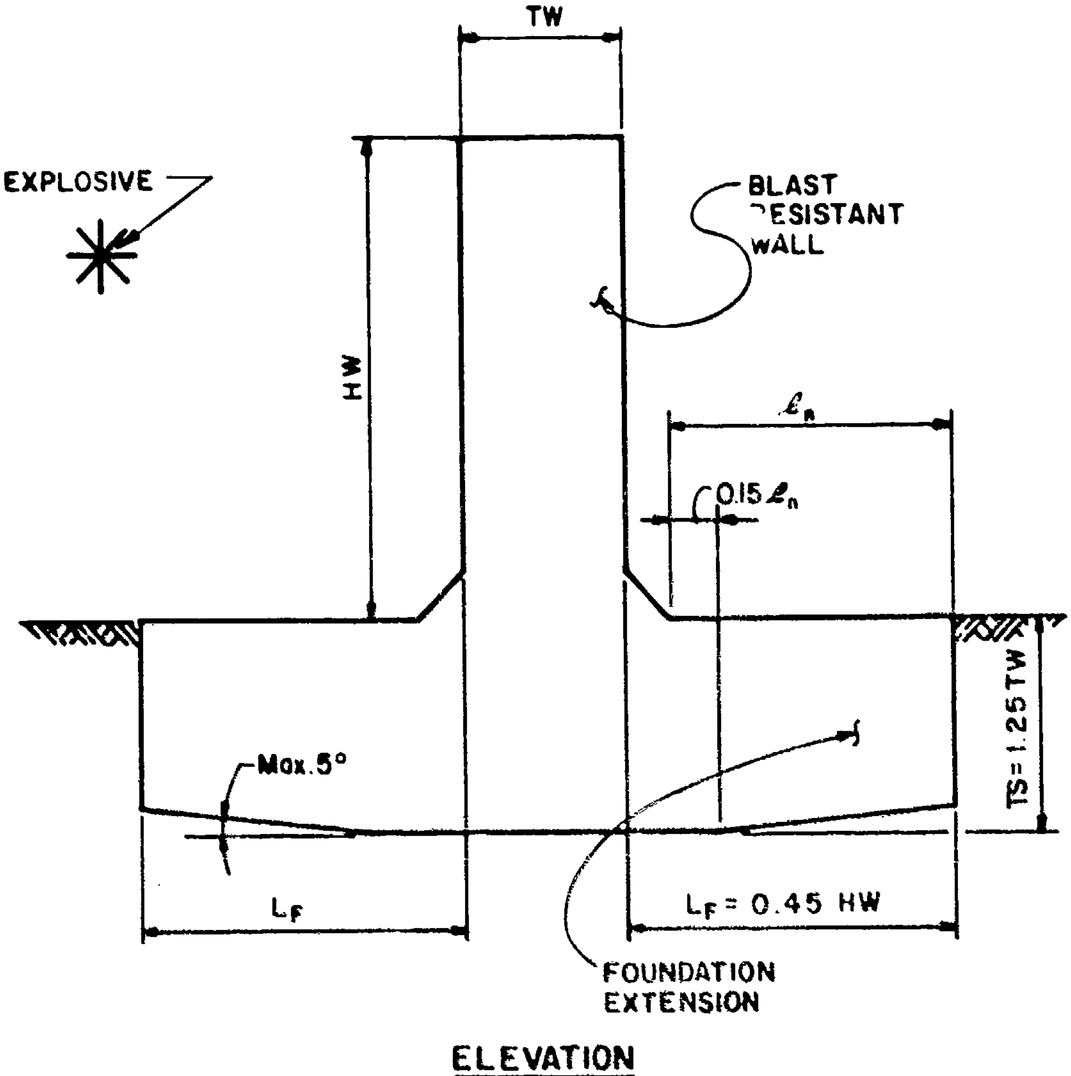


Figure C.1 Cantilever wall barrier - Estimated foundation dimensions.

estimated length of the extension is too short to prevent overturning, the foundation should be extended an equal amount on both sides of the wall. This is more efficient than extending the foundation outward from one side of the wall only.

Single cell barriers, as a rule, do not require long thick foundation extensions to prevent overturning. The foundation thickness is established by providing the foundation with sufficient bending strength (in both directions) to completely develop the ultimate strength of each blast wall (backwall and sidewalls, see Figure C.2). Generally, this is accomplished by making the "d_c" of the foundation equal to the maximum value of "d_c" for any of the blast walls ("d_c" is the distance between centroids of the tension and compression reinforcement in an element, see Figure C.2). With "d_c" established, the areas of reinforcing steel (in both directions) are computed (using Equation C.4) by equating the ultimate moment capacities of the foundation with the moment capacities of the blast walls (see Figure C.3). Using the computed areas of steel, the sizes of the actual reinforcing bars are chosen and the thickness of concrete cover (top and bottom) is determined according to the provisions of Section 7.14 of the ACI Code (Reference 8). The total thickness of the foundation is the sum of "d_c" (for the foundation), the diameter of the outermost reinforcing bar and the thickness of the top and bottom concrete cover. The length of the foundation extension is established by providing the anchorage required for the reinforcing steel in the concrete. As the foundation design is finalized, after several overturning analyses, the required moment capacity of the foundation (and area of reinforcing steel) within the cell, can be reduced, as illustrated in Figure C.3, by subtracting from the moment capacity of the wall the maximum moment developed in the foundation extension during the overturning response to the blast loads.

In some protective structures, the simple type foundation extension required to prevent overturning of the structure, will be excessively long and thick. This usually occurs in the following situations: (1) cantilever walls with heights exceeding 20 feet and (2) single cell barriers in which the ratio of the cell height to the length of the foundation, within the cell, exceeds 1. Examples of these conditions are illustrated in Figures C.4 and C.5. In these situations, backup structural elements (such as the buttress walls shown in Figures C.4 and C.5) are required to support the foundation. For the purpose of performing the overturning analysis, an estimate of the foundation thickness can be made by following the guidelines suggested in the preceding paragraph for single cell barriers. In this situation, however, the moment capacity provided for the foundation is one half of the

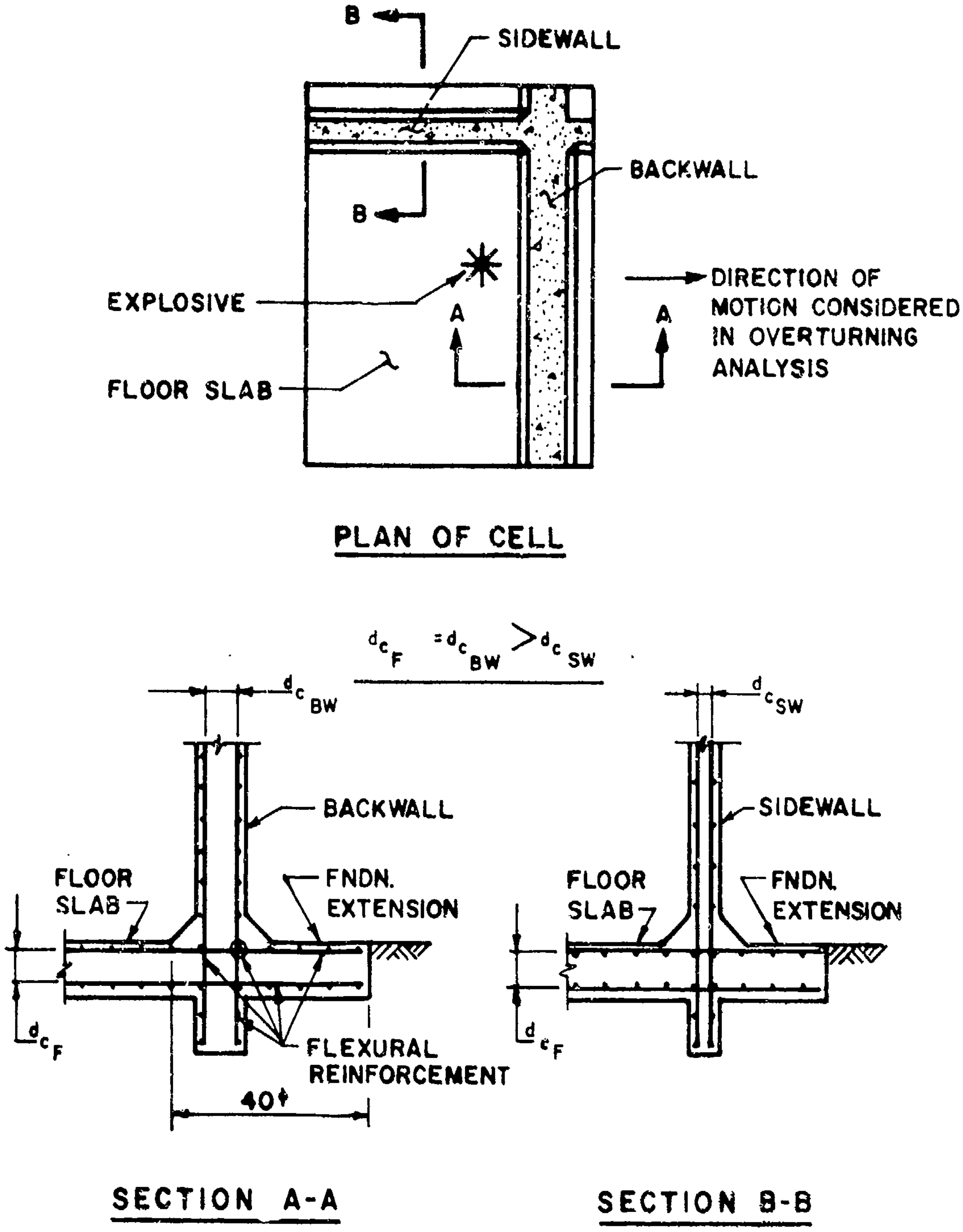


Figure C.2 Single cell barrier - Estimated Foundation dimensions

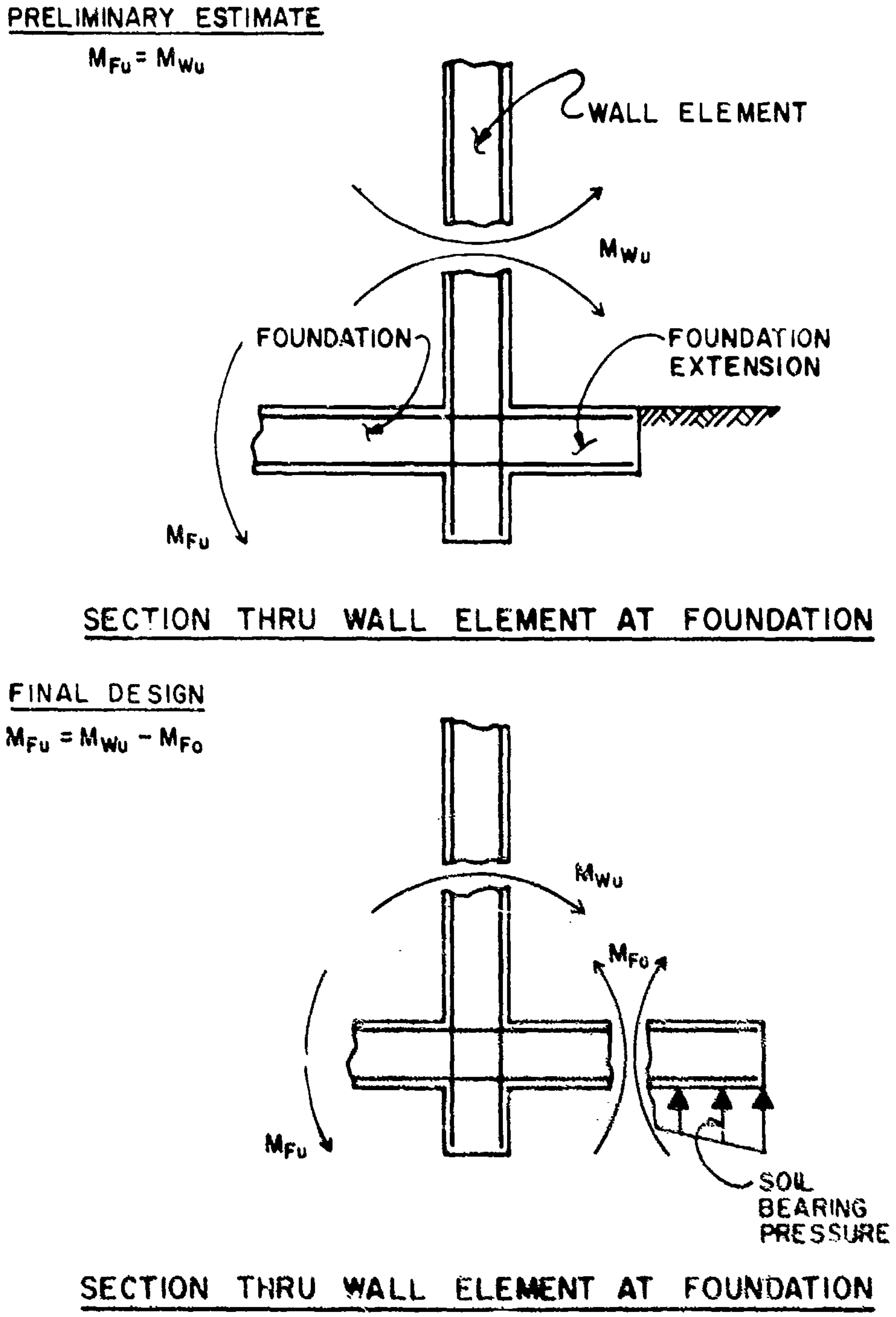


Figure C.3 Single cell barrier - Moment balance at junction of backwall and foundation slab

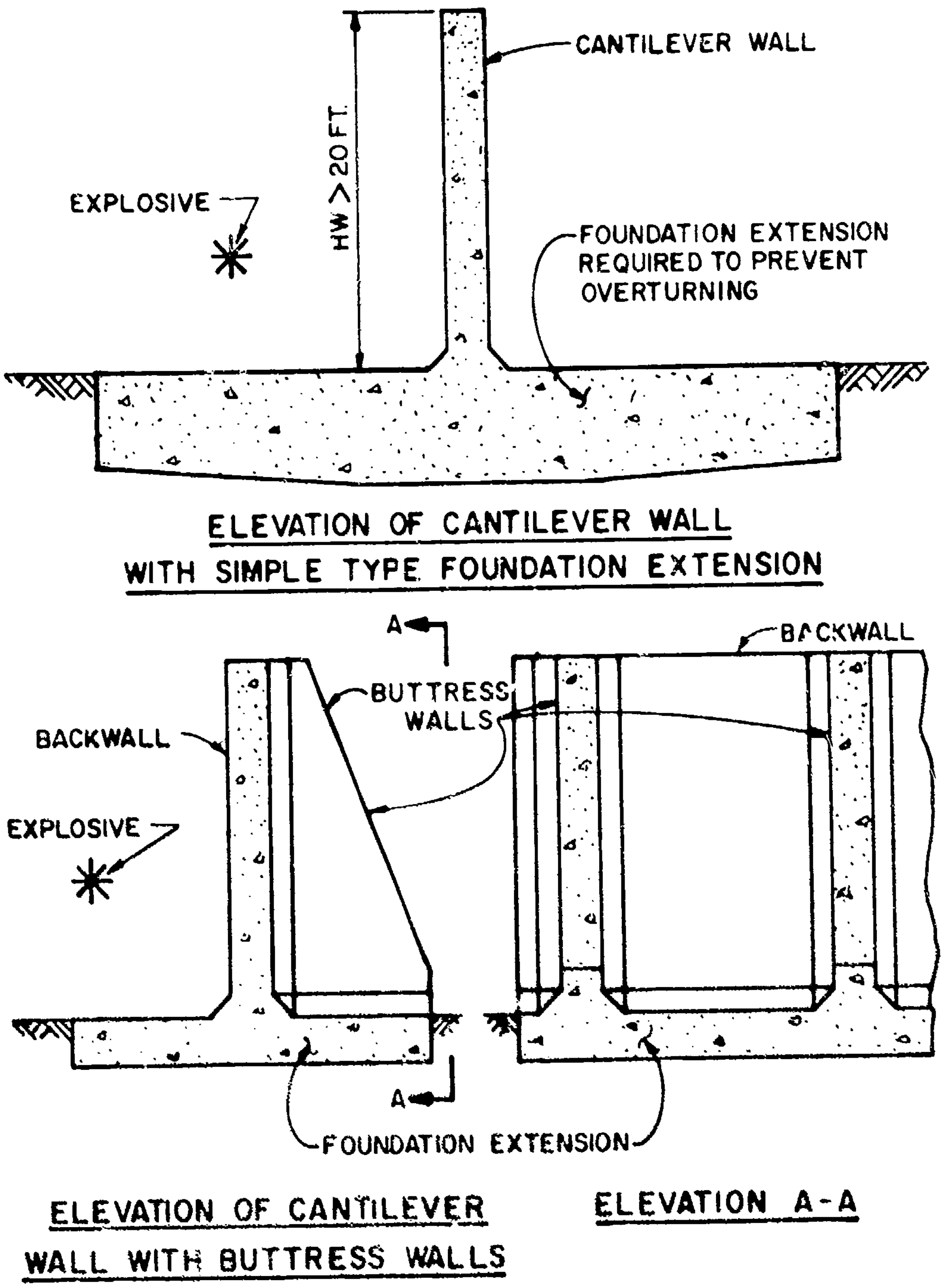


Figure C.4 Cantilever wall barrier with foundation supported by buttress walls.

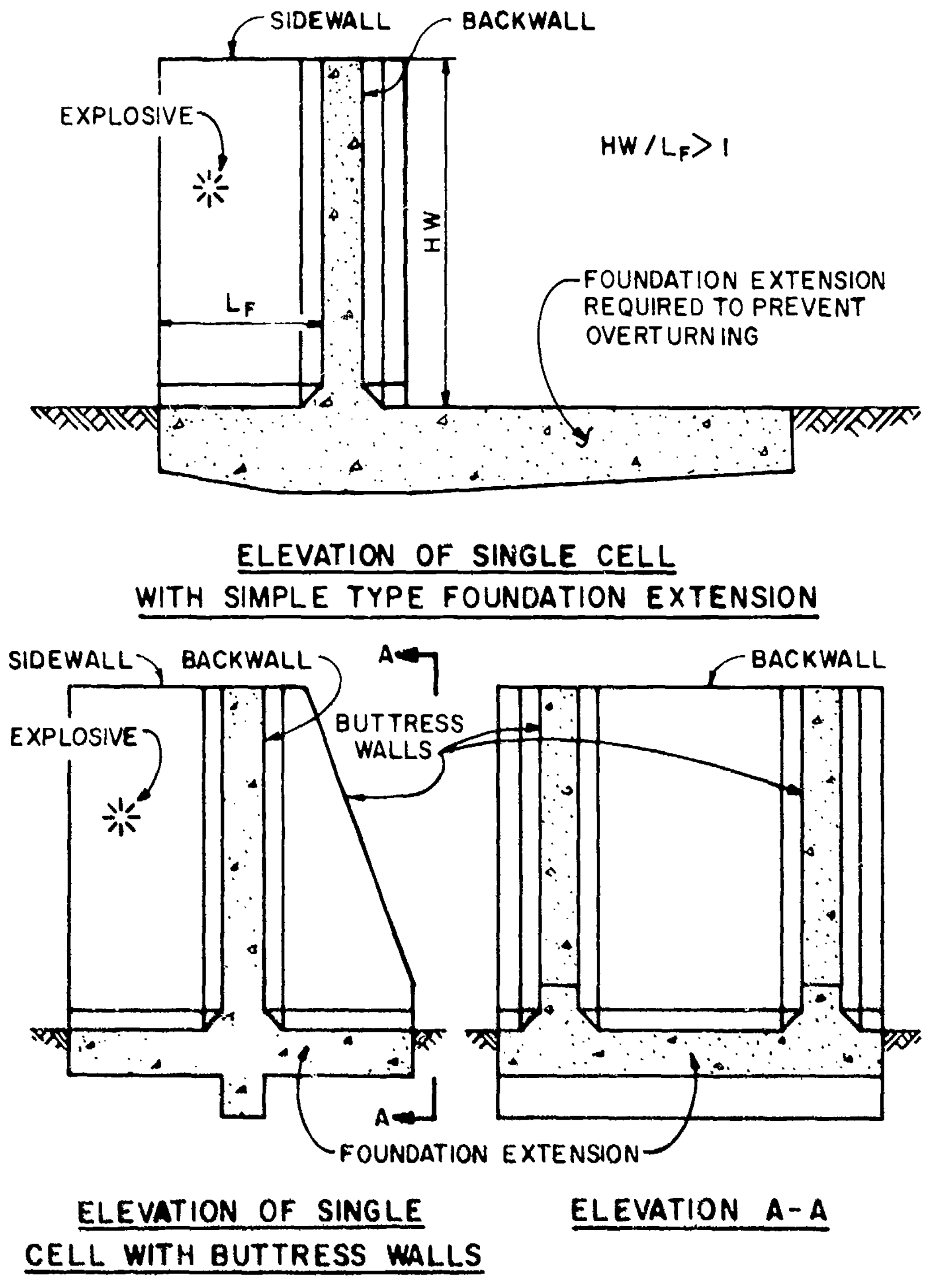


Figure C.5 Single cell barrier with foundation supported by buttress walls.

moment capacity of the backwall element, since the rigid supports provided for the foundation extension (see Figures C.4 and C.5) produce a condition in which the ultimate bending strength of the foundation extension slab can be developed. Generally, the length of the foundation extension required will be approximately 40 percent of the height of the wall.

Using the estimated dimensions of the foundation presented in the preceding paragraphs, an analysis should be performed to determine the bearing pressure in the soil beneath the structure for the working load condition (dead and live loads). Decisions regarding the manner in which these loads are to be transferred to the supporting soil (i.e., through foundation bearing on soil or through piles) should be made prior to performing the overturning analysis in order to insure that the finalized foundation design is adequate for this load condition.

C.2.3 Correlation of Soils Data and Overturning Design Criteria

As discussed in Section 4.3 of this report, the soil data usually available to the designer is limited to the results of a minimum of shallow test borings together with a visual description of the soil encountered and the blow count from standard penetration tests. In Tables 1 and 2 of Section 4, a correlation of soil properties with the above data was presented. This correlation provides the designer with the means of determining the properties of the soil (at the construction site) for use in the overturning analysis.

The properties of the soil grossly affect the response of the structure. Therefore, these properties have a large impact on the foundation design. Tables 1 and 2 of Section 4 provide for a particular soil, the properties in the soft or loose condition and the compact or hard condition. The actual condition of the soil at a given site will be somewhere between these extremes.

In order to account for the most severe design conditions for both overturning and strength, the structure is analyzed for both conditions of the soil. The response of the structure on the soft condition of the soil establishes the length of the foundation extension required to prevent overturning, whereas the response of the compact condition of the soil dictates the thickness of concrete and amount of reinforcing steel required for the foundation extension to resist the bearing pressures developed in the soil beneath the structure.

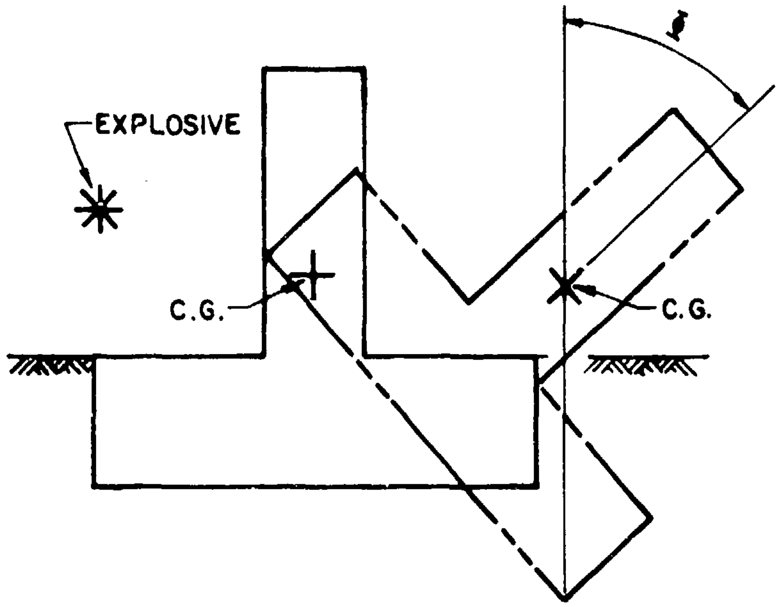


Figure C.6 Displaced configuration of structure at incipient overturning.

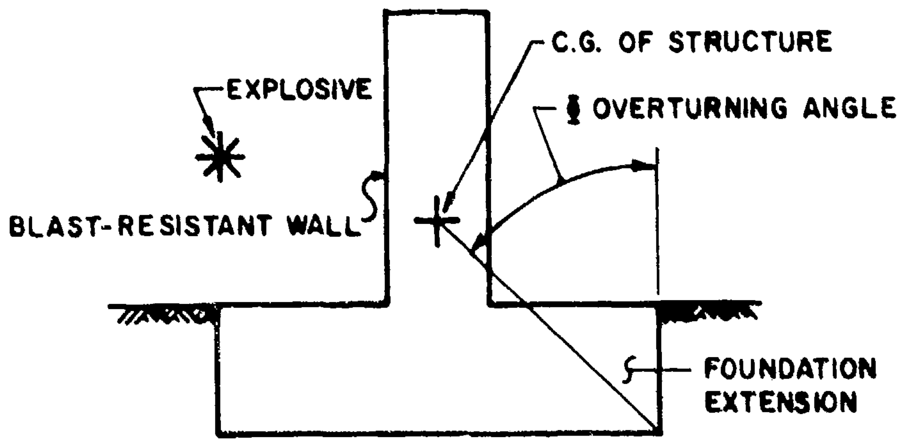


Figure C.7 Definition of overturning angle.

Generally, rotations of the structure that approach the point of incipient overturning (as defined in Figure C.6) can be tolerated. Therefore, for the design to be efficient, the peak response of the structure on the soft soil should approach incipient overturning. To insure that the structure will not overturn on the soft soil, the peak rotation of the structure on the compact soil is limited to a percentage of the overturning angle (defined in Figure C.7). The results of several design studies indicate that limiting the peak rotation of the structure on the compact soil to a value of approximately 40 percent of the overturning angle will insure that the structure will not overturn, but will approach a peak response of incipient overturning on the soft soil.

The guidelines presented in the previous paragraph are utilized in the design of the foundation extension by performing a series of overturning analyses. After each analysis, the dimensions of the foundation extension are modified, according to the analysis results. This process is repeated until the results of the analyses, for both soil conditions, indicate that the structure rotates to 40 percent of its overturning angle on the compact soil and does not overturn on the soft soil. This procedure is generally applicable to cantilever wall barriers only. However, it can be applied to single cell barriers provided it does not alter the foundation dimensions to the extent that the following minima are not maintained: (1) the minimum length of the foundation extension required for anchorage of the reinforcement in the concrete or (2) the minimum required plan size to transfer the conventional (dead and live) working loads to the supporting soil without exceeding the allowable bearing pressure for the soil. In the event that piles are utilized, Item (2) can be ignored.

The criteria presented in this section and the data presented in Section 4.3 are intended to be used when more reliable soil data are not available. If more reliable data are available, the structure should be analyzed for the specific properties derived from the data. In this situation, the structure can be permitted to rotate to the point of incipient overturning under the action of the blast.

C.3 Design Criteria for Foundation Extensions

C.3.1 Introduction

As the structure responds to the blast loads, high bearing pressures are developed in the soil beneath the foundation extension. These pressures impart shears and bending moments in the foundation extension for which the foundation slab must be

designed. Since shear reinforcement is not utilized, the thickness of the member will generally be dictated by the shear design. Basically, the design involves determining the thickness of concrete required to resist the peak shear load and the area of reinforcing steel needed to resist the maximum bending moments.

There are two types of foundation extensions utilized with protective structures. Most structures require only the simple type extension shown in Figures C.1 and C.2. The extension behaves essentially as a cantilever beam. Generally, a short deep member will be required to resist the applied shears. In most cases, the design of the simple type extension will fall under the deep beam provisions of Section 11.9 of the ACI Code (Reference 8).

Tall barriers will generally require a more complex foundation system such as those shown in Figures C.4 and C.5. In these situations, the foundation behaves as a two-way member with a portion of the applied soil bearing pressures reacted by the buttress walls. The two-way action will generally result in a thinner foundation slab which is designed using the methods and data of Section 5, Reference 1.

In the following sections, the equations for the allowable concrete shear stresses are presented for both types of foundation extensions. Presented also are the equations for computing the ultimate unit resisting moments of the foundation. In addition, minimum areas of flexural reinforcement are specified.

C.3.2 Thick Foundation Extension

The term "thick foundation extension" applies to members having a l_n/d, ratio of less than 5 where the term "l_n" is the clear span of the member to the face of the support (see Figure C.8) and "d" is the distance from the extreme compression fiber to the centroid of the tension reinforcement. Generally, the simple type foundation extension will usually fall into this category.

The allowable shear stress carried by the concrete is computed according to the following equation:

$$v_c = \phi[3.5 - (2.5M_{cr})/V_u d][1.9\sqrt{f'_c} + 2{,}500\rho_w(V_u d/M_{cr})] \tag{C.1}$$

except that the term "$[3.5 - (2.5M_{cr})/V_u d]$" shall not exceed $6\sqrt{f'_c}$. The terms in the equation are defined on the following page.

ϕ = capacity reduction factor

= 0.85 for all sections

v_c = nominal permissible shear stress carried by the concrete, psi

M_{cr} = applied design load moment at the critical section, in-lb

V_u = total applied design shear force at critical section, lb

d = distance from extreme compression fiber to centroid of tension reinforcement, in

f'_c = specified compressive strength of concrete, psi

p_w = ratio of area of flexural reinforcement to area of concrete within depth "d" and width "b"

= A_s/bd

b = width of the compression face, in.

This equation, with the exception of the ϕ factor, is presented in Section 11-9 (Equation 11-22) of the ACI Code. To be consistent with the convention utilized in Reference 1, the capacity reduction factor is applied to the allowable stress instead of to the applied stress (which is the method of Reference 8).

The applicability of Equation (11-22) is restricted by the ACI Code to deep beams ($l_n/d < 5$) loaded at the top or compression face (as in simply supported beams). In this report, the applicability of this equation is extended to the simple type foundation extensions (of protective structures) which have an l_n/d ratio of less than 5. These members are cantilevered from the backwall elements and hence, loaded at their tension faces. However, the same load-carrying mechanism (arch action) is developed in the deep cantilevered foundation extension as exists in the deep beam loaded at its compression face (see Reference 9). Therefore, until further test data indicate otherwise, it is considered appropriate, in this instance, to use this equation for determining the permissible shear stress carried by the concrete.

The critical section for shear is taken as 15 percent of the clear span ($0.15\ l_n$) of the member measured from the face

of the support. This value is specified in Section 11.9.3 of Reference 8 and it applies to deep beams loaded by uniformly distributed loads.

C.3.3 Thin Foundation Extension

In situations in which the clear span of the foundation extension is greater than 5 times the "d" distance, the provisions of Section 5.3 of Reference 1 are utilized to determine the permissible shear stress carried by the concrete. Generally, foundation slabs which behave as two-way members will fall into this category.

The permissible shear stress carried by the concrete is computed using Equation 5-10 of the reference. This equation is provided below (Equation C.2). The parameters in the equation are defined in Section C.3.2.

$$v_c = \phi(1.9\sqrt{f'_c} + 2{,}500p_w) < 2.28\phi\sqrt{f'_c} \qquad (C.2)$$

In a thin member, the critical section for shear is taken at a distance of "d" from the face of the support.

C.3.4 Ultimate Resisting Moment

When designing the foundation extension to resist the build-up of soil bearing pressures beneath the structure, the ultimate unit resisting moment of the member is computed utilizing the following equation:

$$M_u = (A_s f_s)[d - (a/2)]/b \qquad (C.3)$$

wherein:

M_u = ultimate unit resisting moment, in-lb/in

A_s = area of tension reinforcement within the width b, in^2

f_s = static design stress for reinforcement, psi

d = distance from extreme compression fiber to tension reinforcement, in

a = depth of equivalent rectangular stress block, in

$= A_s f_s / 0.85 b f'_c$

b = width of compression face, in

f'_c = specified compressive strength of concrete, psi.

Generally, in blast design, an equal amount of flexural reinforcement is provided at both faces of the member. In most cases, however, the ultimate moment capacity of the member can be approximated within acceptable limits, by disregarding the reinforcement in the compression face. Equation C.3 reflects this approximation.

When designing the foundation to develop the strength of a blast wall element, the ultimate unit resisting moment of the member is computed using the following equation:

$$M_u = A_s f_{ds} d_c / b \qquad (C.4)$$

The parameters in this equation are defined in the preceding paragraph with the exception of the quantities "f_{ds}" and "d_c" which are defined below:

f_{ds} = dynamic design strength for the reinforcement which is determined according to the provisions of Section 5-6 of Reference 1, psi

d_c = distance between the centroids of the compression and tension reinforcement, in.

C.3.5 Minimum Flexural Reinforcement

In order to insure the proper structural behavior and also to prevent excessive cracking and deformations under conventional loadings, the minimum areas of flexural reinforcement listed in Table C.1 are recommended. The areas specified are the minimum areas of reinforcement at the tension face of the member. An equal amount of steel should be provided at the compression face also. The quantities specified in the table were extracted from Table 5-1 of Reference 1.

Table C.1 is presented on the following page.

TABLE C.1

MINIMUM AREA OF FLEXURAL REINFORCEMENT

Reinforcement	One-Way Elements	Two-Way Elements
Main	A_s = 0.0025bd	A_s = 0.0025bd
Other	A_s = $0.0010bT_c$	A_s = 0.0018bd

The parameters in the table are defined in Section C.3.3 with the exception of "T_c" which is defined as the total thickness of the member.

C.4 Foundation Design Procedure

C.4.1 Introduction

The method outlined below utilizes the overturning analysis computer program to compute the response of the structure on its supporting soil. The results of the computerized analysis (the time history of the soil bearing pressures) are utilized to design the foundation extension of the structure.

The presentation of the design procedure is divided into two parts. In the first part (Steps 1 through 9), the emphasis is on establishing the length of the foundation extension required to prevent overturning and/or sliding of the structure. This is accomplished by a series of overturning analyses in which the length of the foundation extension is either increased or decreased depending on the results of the previous analysis. The overturning analyses are continued until a satisfactory result is achieved. The second part of the procedure (beginning with Step 10), deals with the methods for designing the foundation extension to resist the peak bearing pressures in the soil. As the overall procedure is intended to be applicable to structures with either the simple (cantilevered) or the more complex type (two-way member supported on three or four sides) foundation extension, the second part of the procedure is divided into two separate presentations. One presentation, consisting of Steps 10a through 15a, deals exclusively with the design of the simple type (cantilevered) extension. A separate presentation, consisting of Steps 10b through 17b, is provided which treats the design of the more complex (two-way member) type foundation extension. The material is presented in this manner because the procedures for designing both types of foundation extensions follow different paths to a final solution. The

design of the simple type extension proceeds in a straightforward manner in which the member is proportioned and the reinforcing steel is supplied to resist the applied shears and bending moments, which are calculated using the soil bearing pressure-time history from the computerized overturning analysis.

The two-way member is designed in an indirect manner. Briefly, the procedure involves determining the amount of flexural reinforcement required for the foundation extension to have an ultimate resistance in bending which is equal to or greater than the peak design load. The ultimate resistance of the element in bending is computed using yield line theory. After the amount of reinforcement is determined, the element is checked for shear and, if necessary, its thickness is increased until the ultimate resistance of the element in shear equals or exceeds the applied load. The applied shears and bending moments are not utilized to design the member. A direct computation of these quantities is, for a two-way element, an extremely complex task requiring the utilization of elastic plate bending theory and numerical methods (such as the finite element technique).

C.4.2 Analysis

The procedure commences after the design of the blast-resistant wall elements has been completed. At this point, the designer has available the following data: (1) the configuration of the structure that is required to confine the explosion, (2) the sizes and design details of all of the blast-resistant wall elements (including thickness, amount of reinforcing steel) and (3) the average unit impulse loads on the wall elements. From this point, the analysis proceeds as follows:

Problem: Design the foundation extension of a protective structure susceptible to overturning and/or sliding.

Procedure:

Step 1. Establish the design parameters:

a. Configuration of structure and design details of blast wall elements

b. Quantities and locations of explosives

c. Available test and descriptive data for soil at construction site

d. Design strength of concrete and reinforcing steel.

Step 2. Based on the configuration of the structure and the guidelines of Section C.2.2, estimate the dimensions of the foundation extension to be utilized in the overturning analysis. For single cell barriers or barriers supported by buttress walls, determine the area of reinforcement required for the foundation to develop the strength of the backwall and sidewalls of the structure.

Step 3. Determine the soil bearing pressures beneath the foundation (using the foundation dimensions estimated in Step 2) for the working (dead and live) load condition.

The foundation must have sufficient plan size to transfer the dead and live loads to the supporting soil without exceeding the allowable bearing pressure for the soil. If the allowable bearing pressure is exceeded, the length and, where feasible, the width of the foundation should be increased in order to provide the plan size required. If an excessively large plan size is required, piles should be used. In any event, the plan size should not be decreased unless the results of the subsequent overturning analysis indicate otherwise.

Step 4. Apply a 20 percent safety factor to the charge weights and determine the average unit impulse loads on the foundation slab within the cell. To determine the loads on the foundations of cantilever wall barriers, utilize the impulse charts and the interpolation method of Appendix A. For single cell barriers, use the methods and data of Reference 1 or the computer program of Reference 2 to determine the impulse loads on the foundation slab. If the structure configuration does not conform to any of those shown in Figure 12, the arrival time and duration of the blast loads on each loaded surface, produced by each explosive charge have to be computed by hand utilizing the procedure and data presented in Appendix B.

Step 5. Correlate the available test and descriptive data for the soil at the construction site with the data of Tables 1 and 2 of Section 4.3 and establish the range of critical soil properties to be utilized in the analysis. The structure is analyzed for both the soft and compact conditions (specified in the tables) of the actual soil. In the event that more accurate data are available, only the actual soil condition need be considered in the analysis.

Step 6. Prepare the input data for the computer program according to the instructions of Section 5. Generally, two data decks are required, each containing the properties (determined in the previous step) for one condition of the soil.

Step 7. Run the two analyses (if two are required) utilizing the overturning analysis computer program.

Step 8. Inspect the results of both analyses and determine for each:

a. If the structure reached its peak response:

In the event that the structure failed to attain its peak response, rerun the analysis utilizing more integration time steps.

b. If the structure overturned:

If the structure overturns, it will do so on the soft condition of the soil. If this occurs, the length of the foundation extension will have to be increased and both analyses rerun.

c. If the structure experienced excessive horizontal (sliding) displacements under the action of the blast:

The horizontal displacements become a factor when explosives are stored nearby. In this situation, there is danger of the structure sliding into the explosives and detonating them, thereby propagating the

explosion. Generally, large sliding motions will occur on the cohesive (clay) soils. This condition is remedied by adding mass to the structure foundation in order to increase the friction forces between the structure and the soil. The added mass will also lower the center of gravity of the structure which causes the toe of the foundation to penetrate further into the soil thereby decreasing the sliding motions. However, this will increase the rotations of the structure and therefore the foundation extension may have to be lengthened, depending on the results of the previous analysis. The revised structure is always re-analyzed for both conditions of the soil.

Further evaluation of the results is deferred until both analyses indicate that the structure attained its peak response and will neither overturn nor translate large distances under the action of the blast.

Step 9. Once the conditions of Step 8 are satisfied, evaluate the results of the analysis in order to determine if any further modification of the foundation dimensions is required. These added modifications are required when the analysis indicates that the structure attains peak rotations which are far less than what is permitted. In most cases, analyses of the structure supported by both a soft and a compact soil are required and generally, the foundation extension can be shortened until the results of the analyses indicate that the structure rotates to 40 percent of its overturning angle on the compact soil, provided the decreased length of the foundation extension does not violate the design criteria in Section C.2.3.

In the event that more accurate soils data are available, the structure can be allowed to rotate to the point of incipient overturning (see Figures C.6 and C.7).

C.4.3 Design: Simple Type Foundation Extension

Once satisfactory results are obtained from the analysis, the detailed design of the foundation extension commences. The procedures utilize the bearing pressure time history printed out by the computer program. In most cases, analyses are performed for the structure supported on both the soft and compact conditions of the actual soil. The foundation extension is designed for the bearing pressures developed on the compact soil.

This section treats the design of simple type (cantilevered) foundation extensions of the type normally utilized with cantilever wall barriers and single cell barriers. In this section, the instructions (steps) are labeled with the suffix "a" (i.e., Step 10a.) to distinguish them from the instructions presented in the next section.

The computation proceeds as follows:

Step 10a. Determine the location of the critical section for shear according to the provisions of Section C.3.

Step 11a. Determine from the printout of the soil bearing pressure time history, the peak shear (and corresponding bending moment for thick sections, $l_n/d < 5$) at the critical section for shear and the peak bending moment at the face of the support.

These quantities (V_u, M_{cr} and M_u) are computed by the program for cantilever wall barriers. For other structural configurations, these quantities must be computed manually.

Generally, the bearing pressure distributions at several time stations are investigated to determine the peak shear and bending moments. When the computation is performed by the computer program, the bearing pressure distribution at every integration time station is investigated.

The peak shear usually occurs when the point on the foundation with zero bearing pressure approaches the critical section for shear on

the extension. Figure C.8 shows the configuration of the bearing pressure distribution curve and identifies the design parameters and critical sections for shear and bending. The figure also illustrates the order in which the bearing pressures are printed out by the computer program.

Figure C.9 shows the free body diagrams for computing the peak shear and bending moment on the foundation extension. The shear is determined by computing the area within the bearing pressure distribution curve. The bending moment is determined by computing the moment of the area within the bearing pressure distribution curve about the desired location on the extension.

Step 12a. Determine the allowable shear stress that can be carried by the concrete using the equations provided in Section C.3.

Step 13a. Determine the thickness of concrete ("d") required to carry the peak applied shear load.

$$d = V_u/v_c$$

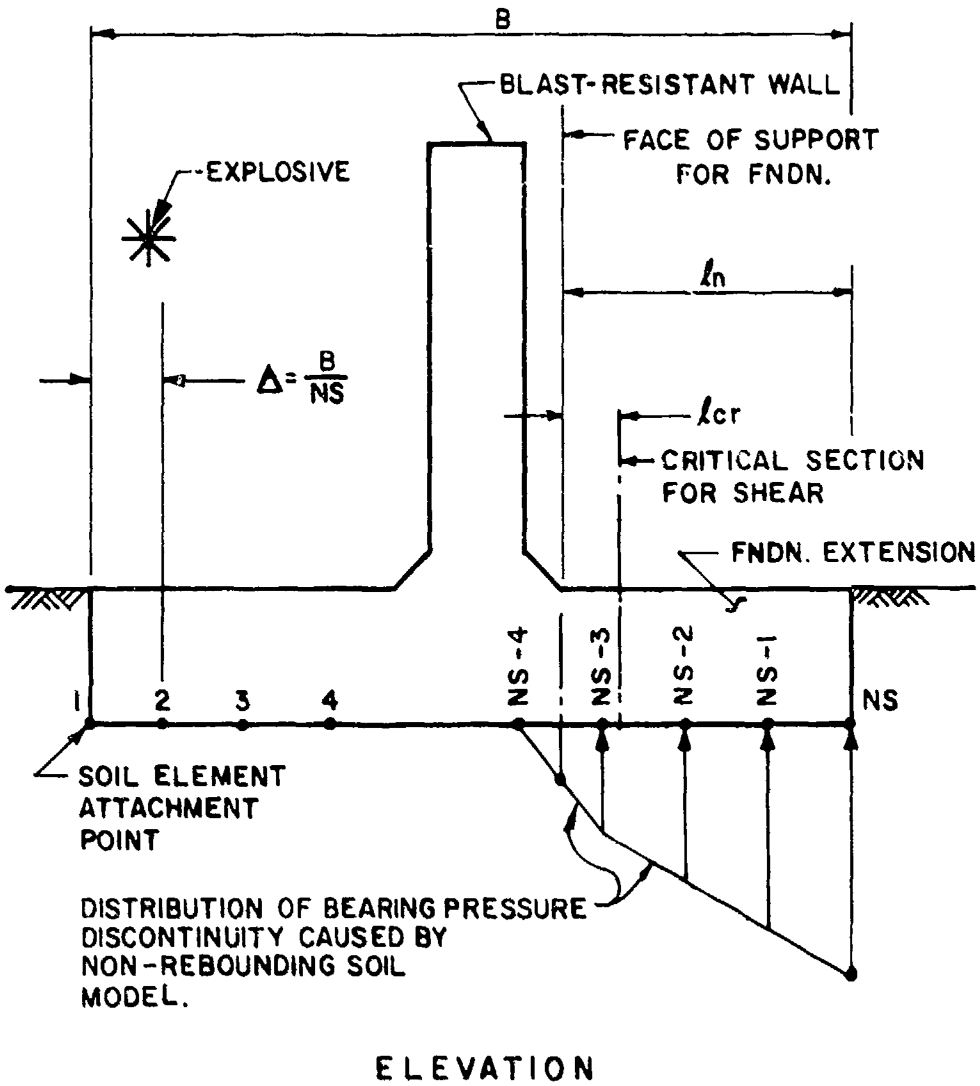
where:

d = distance from extreme compression fiber to tension steel, in

V_u = peak applied shear load, lb/in

v_c = permissible shear stress carried by concrete, psi

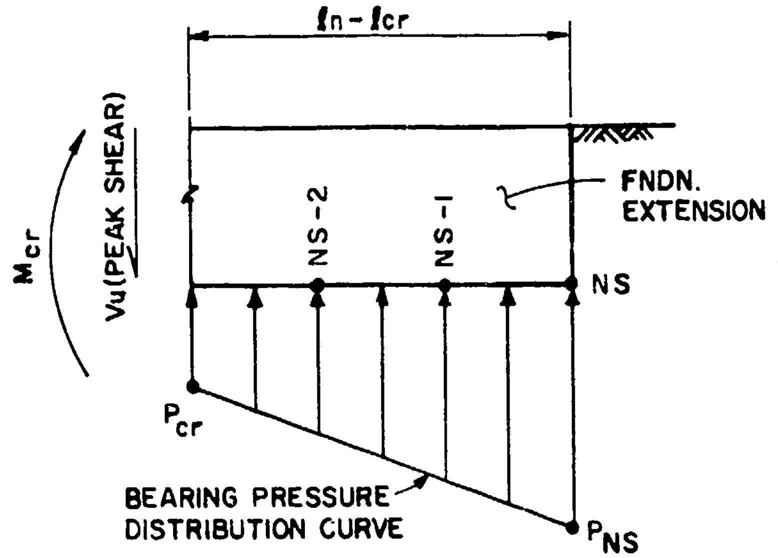
Step 14a. Determine the area of the flexural (main) reinforcement required using the peak applied bending moment (at the face of the support) in Equation (C.3). At the same time, compute the area of reinforcement, perpendicular to the main reinforcement, according to the provisions of Table C.1.



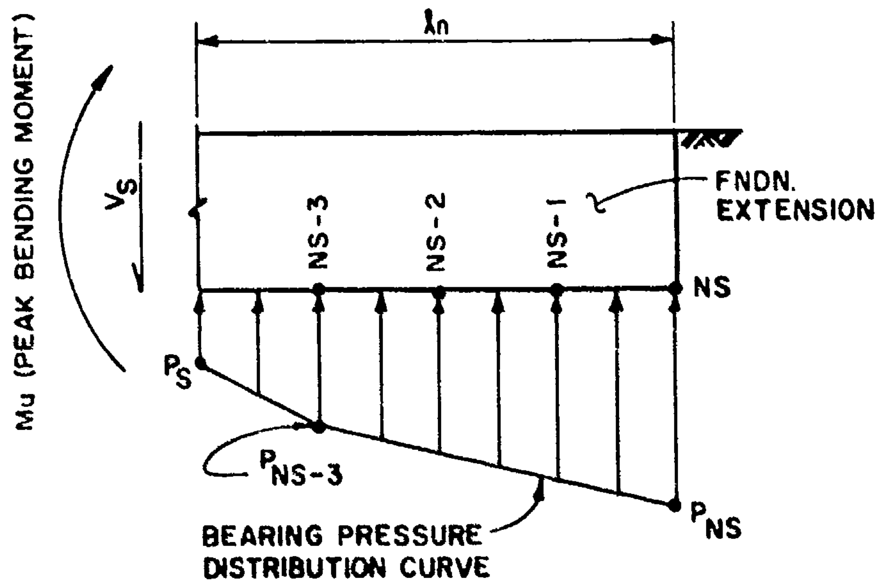
NOTES:

1. NS DENOTES NUMBER OF SOIL ELEMENTS
2. THE NUMBERS ON THE BOTTOM FACE OF THE FOUNDATION CORRESPOND TO THE NUMBERS PRINTED OUT BY THE COMPUTER PROGRAM AT THE TOP OF EACH PAGE CONTAINING THE SOIL BEARING PRESSURE-TIME HISTORY.

Figure C.8 Design parameters - Simple type foundation extension.



FREE BODY DIAGRAM FOR SHEAR COMPUTATION



FREE BODY DIAGRAM FOR BENDING MOMENT COMPUTATION

Figure C.9 Free body diagrams of simple type foundation extension for computation of peak shear and bending moment.

Step 15a. Determine the actual thickness of the foundation using the following equation:

$$T_c = d + d_b/2 + c \qquad \text{(C.5)}$$

where:

T_c = thickness of foundation, in

d = distance from extreme compression fiber to centroid of tension reinforcement, in

d_b = diameter of tension reinforcement bar, in

c = thickness of bottom concrete cover specified in Section 7.14 of Reference 8 (always 3 inches)

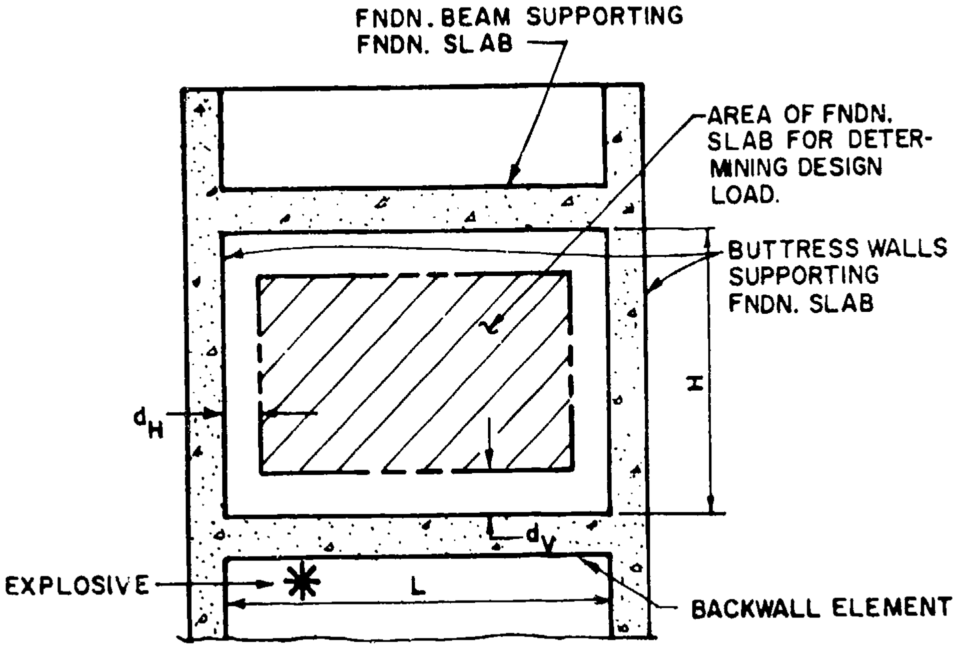
Depending on the configuration of the structure, a significant decrease in the foundation thickness could result in a substantial increase in the peak rotation of the structure. This is generally the case with cantilever wall barriers; therefore, if the foundation thickness computed is much less than the thickness used in the overturning analysis, repeat the analysis with the revised foundation thickness in order to verify the final design. The verification analysis is generally not required for single cell barriers.

This completes the design of the simple type foundation extension.

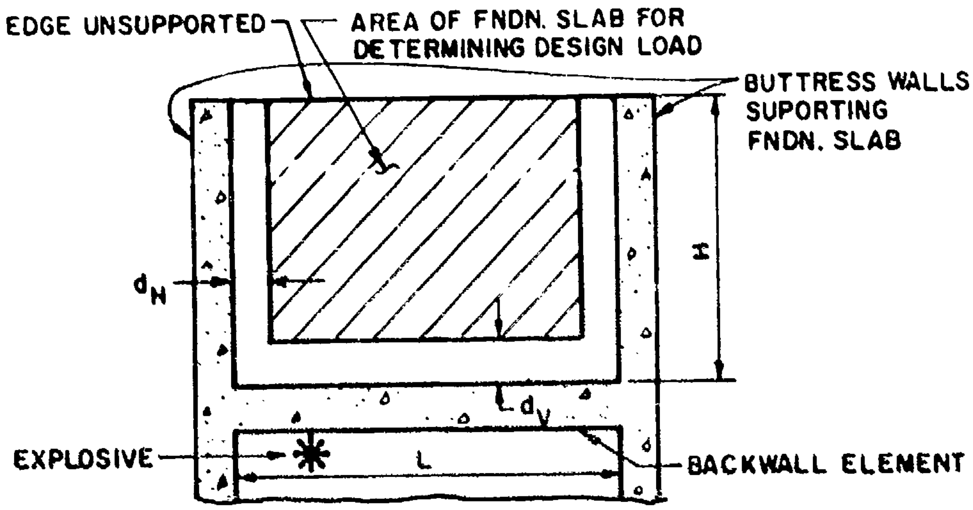
C.4.4 Design: Two-Way Foundation Extensions

This section treats the design of foundation extensions which behave as two-way members. In this section, the instructions (steps) are labeled with the suffix "b" (i.e., Step 10b.) to distinguish them from the instructions presented in the previous section.

The computation commences upon the satisfactory completion of the overturning analyses (Step 9).



FNDN. EXTENSION SUPPORTED ON FOUR SIDES



FNDN. EXTENSION SUPPORTED ON THREE SIDES

Figure C.10 Plan views of foundation extensions supported on three and four sides.

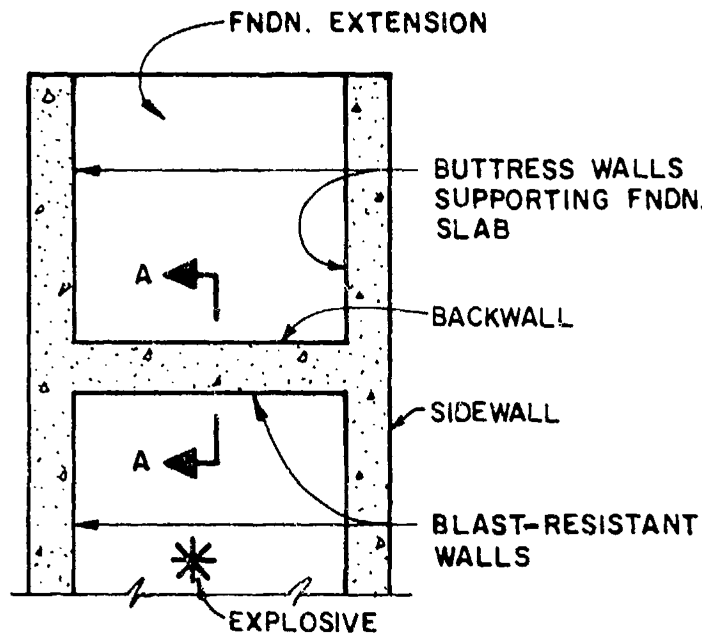
The computation proceeds as follows:

Step 10b. Determine, from the output of the computer program, the design loading for the foundation extension. The design loading is defined as the soil bearing pressure distribution corresponding to the maximum total load on the portion of the surface area of the foundation extension which is beyond the critical section for shear ("d" from support) as shown in Figure C.10.

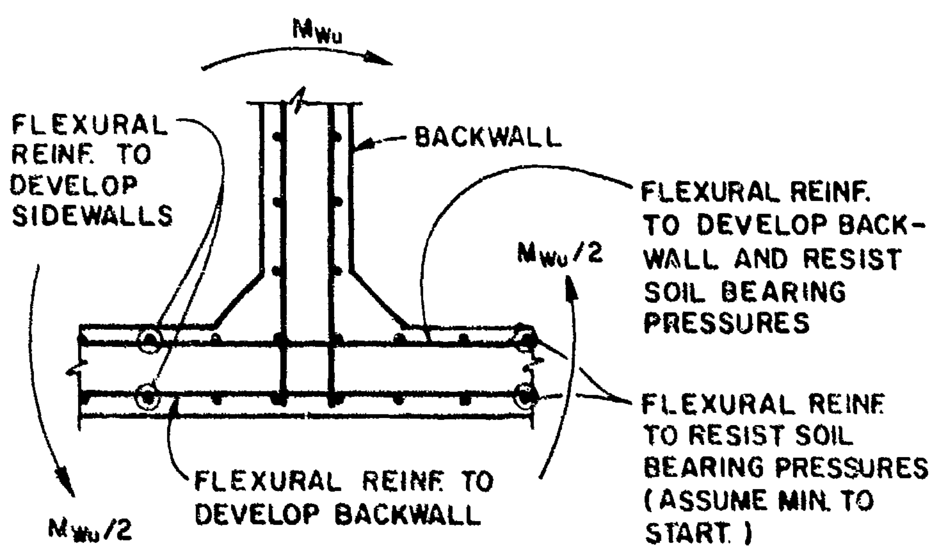
Step 11b. Establish the initial amount of flexural reinforcement (for the foundation extension) to be used as a starting point in the design computations. The thickness of the foundation and the amount of flexural reinforcement in the direction perpendicular to the backwall element (see Figure C.11) are determined in Step 2 on the basis of providing the ultimate moment capacity required to develop the strength of the blast walls. For the reinforcement parallel to the backwall element, utilize the minimum area of reinforcement specified in Table C.1. The same amount of reinforcement should be supplied at both faces of the member. If the area of reinforcement perpendicular to the backwall is less than the minimum quantity specified for the main reinforcement, the area of reinforcement parallel to the backwall must be greater than the specified minimum for the main reinforcement.

Step 12b. Compute the ultimate positive and negative bending moment capacities in both directions for the foundation extension using Equation C.3.

Step 13b. Utilizing yield line theory, compute the ultimate resistance in bending of the foundation extension. The computation is performed for a load distribution which has the same characteristics as the design load acting on the foundation. Section 5-10 of Reference 1 presents a discussion of yield line theory and illustrates the computation of the ultimate resistance for a member subjected to a uniform load. The same methods



PARTIAL PLAN OF FNDN.



SECTION A-A

Figure C.11 Single cell barrier with buttress walls - Moment balance at junction of backwall and foundation slab.

are utilized in this problem for a member loaded by a trapezoidal load distribution.

Step 14b. Compare the computed resistance with the actual design load. If the computed resistance is greater than the applied load, go on to the shear design (Steps 15b and 16b).

If the computed resistance is less than the applied load, increase the area of reinforcement in the direction parallel to the backwall element and recompute the ultimate resistance. Repeat this computation until the computed resistance of the foundation extension equals or exceeds the applied load.

Step 15b. Based on the final location of the yield lines (computed in Step 14b.), compute the shear stress, produced by the design load, at the critical section for shear for each sector of the foundation (see Figure C.12). The design shear load for a sector is simply the applied load on the portion of the sector beyond the critical section for shear. The applied stress is computed by dividing the design shear load for the sector by the product of the width of the sector at the critical section and the depth of concrete ("d").

A discussion and illustration of the shear stress computation is presented in Section 5-20 of Reference 1.

Step 16b. Compute the allowable shear stress for the concrete using Equation C.2. Compare the allowable shear stress with the applied shear stress.

If the applied shear stress is less than the allowable shear stress, proceed to the next step.

If the applied shear stress is greater than the allowable shear stress, increase the thickness of the foundation and proportion the areas of the reinforcement such that the revised foundation has roughly the same

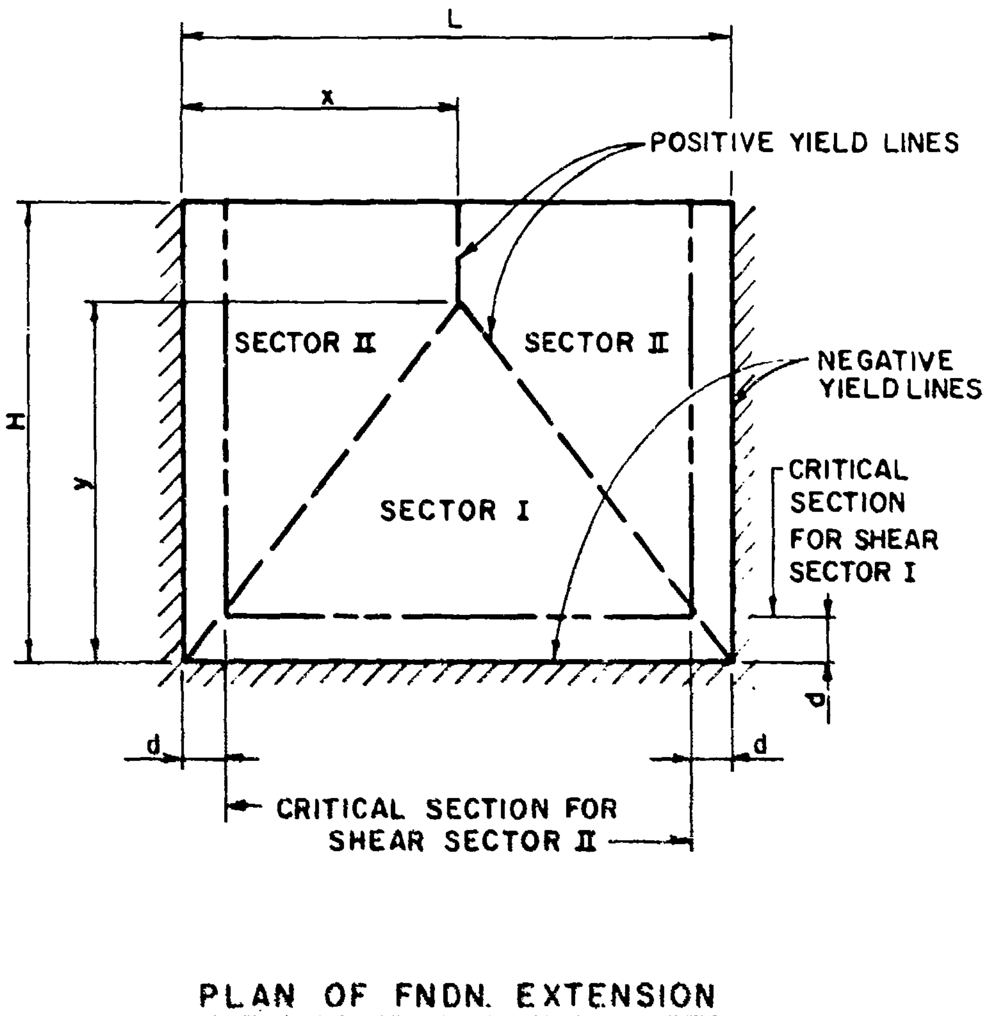


Figure C.12 Design parameters - Foundation extension supported on three sides.

bending moment capacities as the original foundation. If, in proportioning the areas of reinforcement, the area of the steel in one or both directions falls below the minima specified in Table C.1, use the minimum areas.

Recompute the following for the revised foundation:

1. Yield line location

2. Ultimate bending resistance of the member

3. Shear stress at the critical section for shear at both sectors.

Repeat the above computation cycle until the results indicate that the applied shear stress is less than the allowable shear stress for the member.

Step 17b. Compute for all sectors the shear load at the face of the supports. Using these shear loads, design the elements (such as buttress walls or foundation beams) supporting the foundation extension.

This completes the design of the two-way foundation extension.

C.5 Example C.1: Cantilever Wall Barrier

Example C.1: Design of the foundation extension for a cantilever wall barrier.

Required: Determine the length, thickness and amount of reinforcing steel required for the foundation extension of a cantilever wall barrier.

Step 1. Given:

a. Configuration of the structure and details of the wall which is designed to the incipient failure condition (Figure C.13).

b. Quantity of explosive: three charges each weighing 1,900 lbs (TNT) and located as shown in Figure C.13.

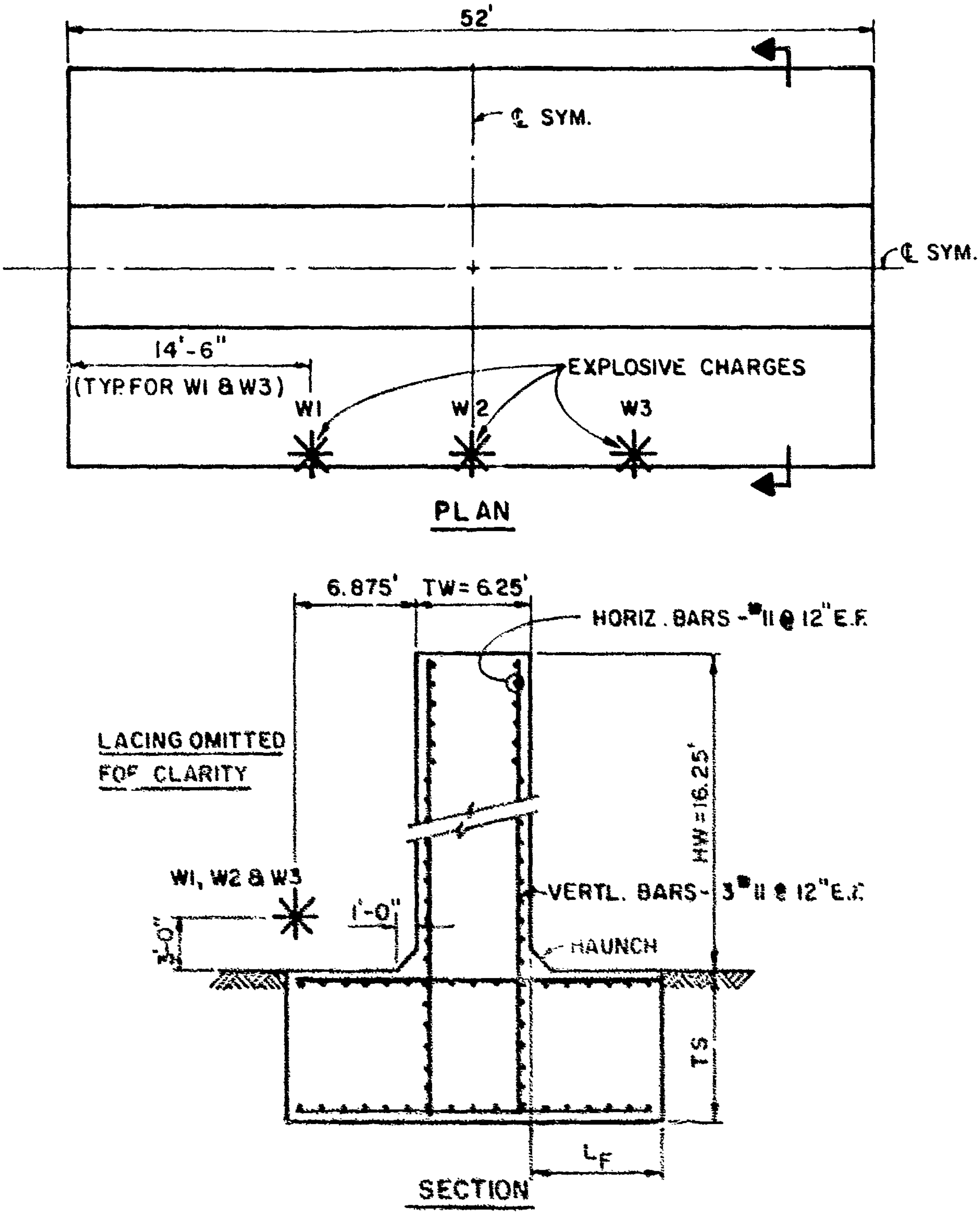


Figure C.13 Example C.1: Dimensions of structure, design details of backwall and charge locations.

c. Soil data available:

Description: Gravel

Compaction: Medium

Blow count: 40

Allowable bearing pressure: 5 tons/ft^2

d. Design strength for building materials:

1. Concrete f'_c = 4,000 psi

2. Steel f_y = 60,000 psi

<u>Step 2</u>. Estimate the dimensions of the foundation extension to be used in the overturning analysis.

Thickness of wall: (TW) = 6.25 ft

Height of wall: (HW) = 16.25 ft

Estimated thickness of foundation extension:

TS = 1.25(TW) = 1.25(6.25) = 7.81 ft

Use 7.83 ft = 7 feet 10 inches

Estimated length of foundation extension:

L_F = .45(HW) = .45(16.25) = 7.31 ft

Use 7.5 ft = 7 feet 6 inches

For an efficient design, the foundation should be symmetrical about the centerline of the wall.

<u>Step 3</u>. Determine the soil bearing pressure for the weight of the structure.

Estimate weight of structure:

$$W = \frac{\left(16.25(6.25) + [2(7.5) + 6.25](7.83)\right)(52)(150)}{2{,}000}$$

$$= 1{,}045 \text{ tons}$$

Surface area of foundation:

$A = 52[2(7.5) + 6.25] = 1{,}105\ ft^2$

Allowable bearing pressure = 5 T/ft^2

Bearing pressure = 1,045/1,105

$= 0.95\ T/ft^2 < 5\ T/ft^2$

The foundation is adequate for the dead and live load condition.

Step 4. Determine the average impulse loads on the foundation slab.

Design charge weight = 1.20(W)

= 1.20(1,900) = 2,280 lbs

Using the procedure and data provided in Appendix A of the report, the following average impulse loads on the foundation slab are computed:

W_1: $\bar{i}_b$ = 4,400 psi-ms

W_2: $\bar{i}_b$ = 4,800 psi-ms

W_3: $\bar{i}_b$ = 4,400 psi-ms

Since the structure is a cantilever barrier with a configuration similar to the one shown in Figure 12, the remaining loading data, consisting of the times of arrival and load durations, will be computed by the program.

Step 5. Establish the range of critical soil properties to be utilized in the analyses.

The field description of the soil [Item (c) Step 1] and the results of the penetration tests indicate that the soil is a medium compact gravel. Therefore, the structure is analyzed for the properties of the loose and very compact gravels provided in Table 1 of Section 4.3. The properties utilized in the analyses are presented on the following page.

	Loose	Very Compact
Modulus of Elasticity (psi)	3,000	20,000
Poisson's Ratio	0.2	0.15
Friction Factor	0.6	0.70

Step 6. Prepare the input data decks for the computer program.

Since the structure is a cantilever barrier, the "Normal Option" mode of the computer program is utilized to analyze the structure (see Section 5). The input data deck for the analysis of the structure on the compact gravel is presented in Appendix D.

Step 7. Run the analyses on the CDC 6600 computer using the overturning analysis program.

Step 8. Inspect the results of the analyses.

A portion of the printed output for the analysis of the structure on the compact gravel is presented in Appendix D.

The following is a summary of the peak response parameters for the structure on both the loose and very compact gravel.

Loose gravel:

Maximum rotation of structure = 36.20°

Maximum horizontal displacement of foundation = 10.00 inches

Ratio of maximum rotation to overturning angle = 0.70

Very compact gravel:

Maximum rotation of structure = 20.10°

Maximum horizontal displacement of foundation = 3.80 inches

Ratio of maximum rotation to overturning angle $= 0.39$

Inspection of the above tabulation of the results indicates that, in both analyses, the structure:

a. Has reached its peak response.

b. Did not overturn.

c. Did not experience excessive horizontal (sliding) displacements.

Therefore, the design proceeds to the next step.

Step 9. Inspection of the results (peak rotations), summarized in Step 8, indicates that no further modifications of the foundation dimensions for overturning and/or sliding are required; therefore, the design can proceed to the next step.

Step 10a. Determine the location of the critical section for shear.

$l_n = 6.50 \text{ ft} = 78.0 \text{ inches}$

$TS = 7.81 \text{ ft} = 94.0 \text{ inches}$

Assume 4 inches for the bottom cover and tension reinforcement.

$d = 94.0 - 4.0 = 90.0 \text{ inches}$

$l_n/d = 78.0/90.0 = .87 < 5.0$

According to the provisions of Section C.3.2, the foundation is considered a thick section and the critical section for shear is $0.15\ l_n$ from the face of the support.

$l_{cr} = 0.15\ l_n = 0.15(78) = 11.7$ inches from the haunch (see Figure C.14)

Step 11a. Determine the peak shear (and the corresponding bending moment) at the critical section for shear and the peak bending moment at the face of the support. These quantities are computed for the response of the structure on the compact gravel.

Although these quantities are computed by the program, the hand calculation is presented to illustrate the procedure.

The soil bearing pressures at three time stations are investigated. Figure C.14 shows the location of the critical sections for shear and bending on the foundation extension. The locations of the soil element attachment points are also shown in the figure. A portion of the printed output of the bearing pressure time history is provided in Appendix D. The pressure distributions for which the shears and bending moments are computed are shown in Figure C.15. The shears and bending moment are computed for a 1-inch wide segment of the foundation extension.

The computations are presented below:

at t = 0.04286 second:

$$P_{cr} = \frac{(479.5 - 233.6)(46.9)}{(4)(28.3)} + 233.6$$

$$= 335.5 \text{ psi}$$

$$P_s = \frac{(479.5 - 233.6)(35.2)}{(4)(28.3)} + 233.6$$

$$= 310.1 \text{ psi}$$

$$V_u = \frac{(335.5 + 479.5)(66.3)}{2}$$

$$= 27{,}017 \text{ lb/in}$$

$$M_u = \frac{(310.1)(78)^2}{2} + \frac{(479.5 - 310.1)(78)^2}{3}$$

$$= 1{,}286{,}867 \text{ in-lb/in}$$

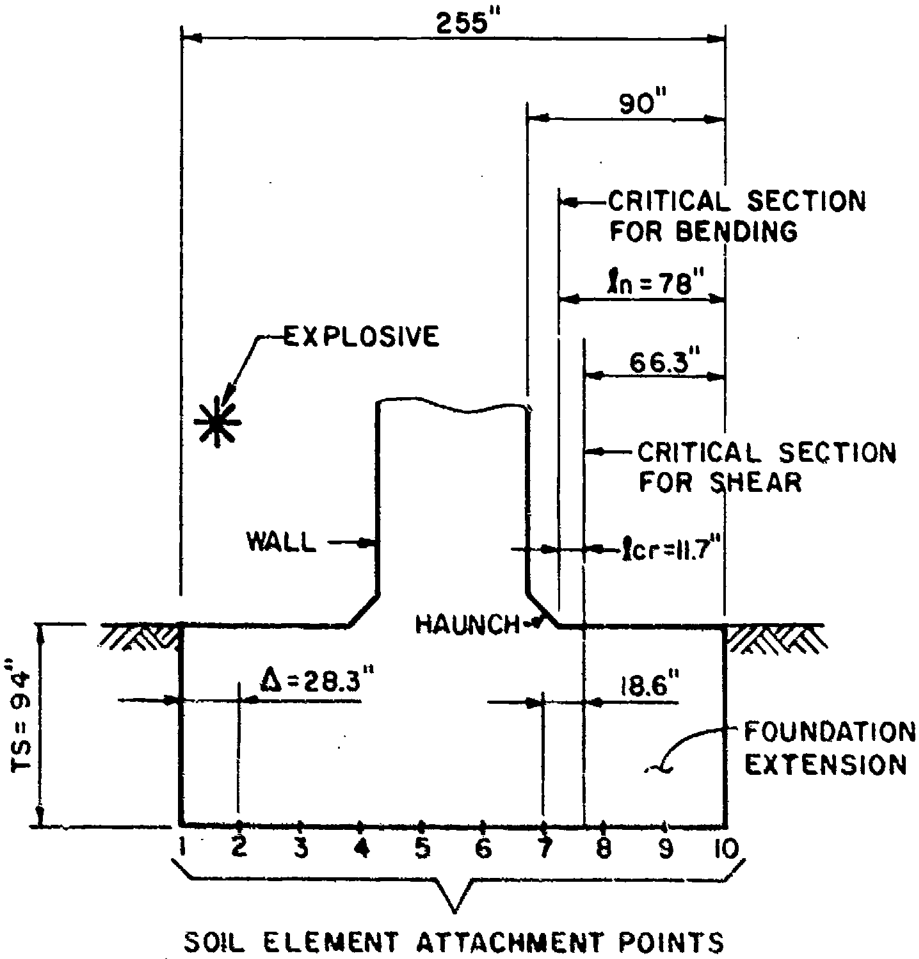


Figure C.14 Example C.1: Locations of critical sections of foundation extension for shear and bending.

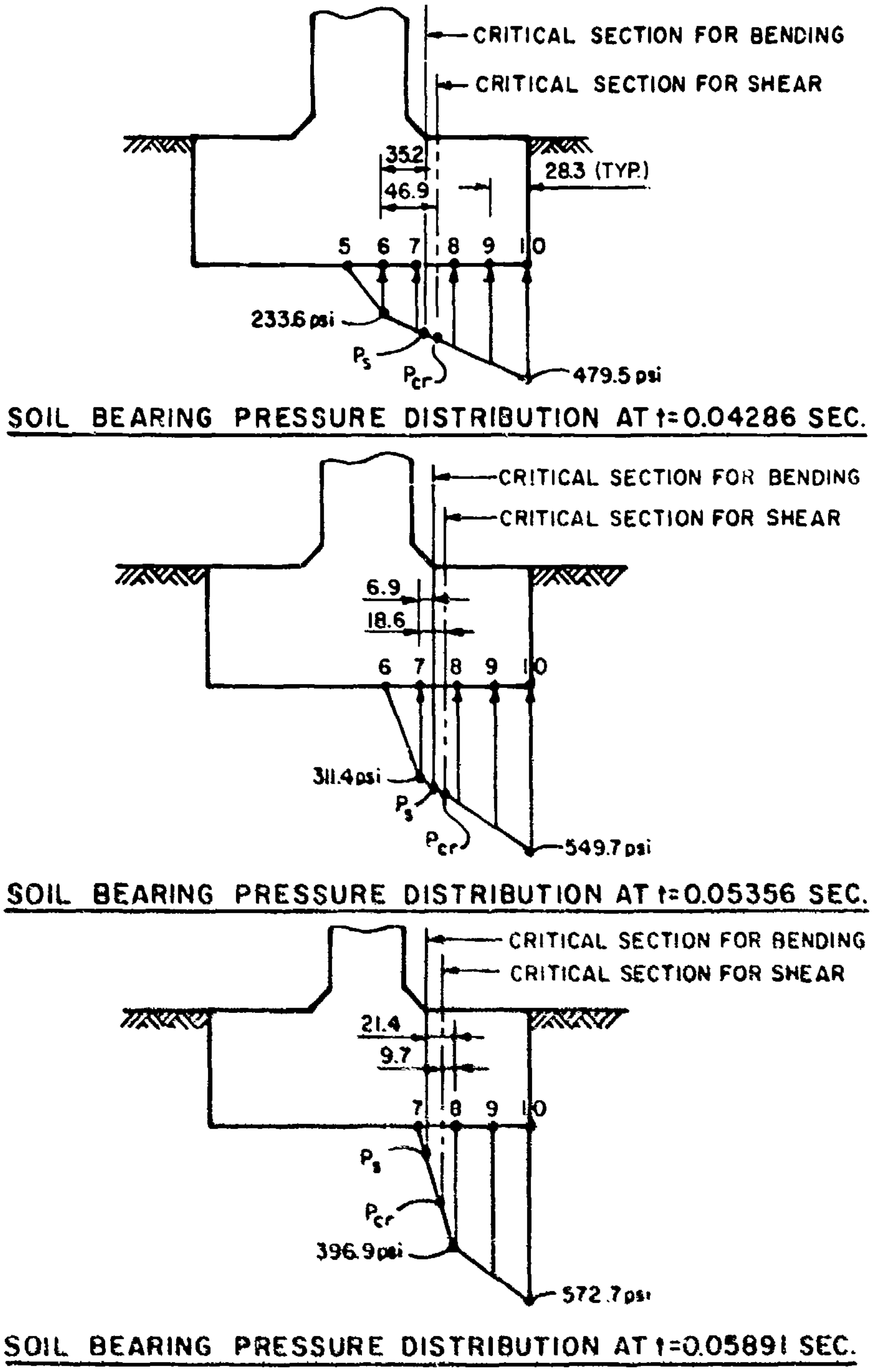


Figure C.15 Example C.1: Foundation extension design loadings.

at t = 0.05356 second:

$$P_{cr} = \frac{(549.7 - 311.4)(18.6)}{(3)(28.3)} + 311.4$$

$$= 363.6 \text{ psi}$$

$$P_s = \frac{(549.7 - 311.4)(6.9)}{(3)(28.3)} + 311.4$$

$$= 330.6 \text{ psi}$$

$$V_u = \frac{(363.6 + 549.7)(66.3)}{2}$$

$$= 30{,}276 \text{ lb/in}$$

$$M_u = \frac{(330.6)(78)^2}{2} + \frac{(549.7 - 330.6)(78)^2}{3}$$

$$= 1{,}450{,}020 \text{ in-lb/in}$$

at t = 0.05891 second:

$$P_{cr} = (18.6/28.3)(396.9)$$

$$= 260.9 \text{ psi}$$

$$P_s = (6.9/28.3)(396.9)$$

$$= 96.8 \text{ psi}$$

$$V_u = \frac{[(572.7 + 396.9)(2)(28.3)]}{2}$$

$$+ \frac{[(396.9 + 260.9)(9.7)]}{2}$$

$$= 30{,}630 \text{ lb/in}$$

$$M_u = \frac{96.8(21.4)^2}{2} + \frac{(396.9 - 96.8)(21.4)^2}{3}$$

$$+ (396.9)[(2)(28.3)][(2)(28.3)/2 + 21.4]$$

$$+ (572.7 - 396.9)(28.3)[(4)(28.3)/3$$

$$+ 21.4]$$

$= 1,478,660$ in-lb/in

The peak shear occurs at t = 0.05891 second.

The corresponding bending moment at the critical section for shear is computed as follows:

$$M_{cr} = \frac{260.9(9.7)^2}{2} + \frac{(396.9 - 260.9)(9.7)^2}{3}$$

$$+ (396.9)[(2)(28.3)][2(28.3)/2 + 9.7]$$

$$+ (572.7 - 396.9)(28.3)[4(28.3)/3$$

$$+ 9.7]$$

$= 1,106,179$ in-lb/in

The peak shear and corresponding bending moment at the critical section for shear are:

$V_u = 30,630$ lb/in

$M_{cr} = 1,106,179$ in-lb/in

The peak bending moment at the face of the support is:

$M_u = 1,478,660$ in-lb/in

Step 12a. Determine the allowable shear stress for the concrete.

Since $l_n/d < 5$, the allowable shear is computed using Equation (C.1).

$V_u = 30,630$ lb/in

$M_{cr} = 1,106,179$ in-lb/in

$d = 90$ inches

$f'_c = 4,000$ psi

p_w = assume minimum from Table C.1

$= 0.0025$

$$v_c = 0.85[3.5 - 2.5(1,106,179)/(30,630)(90)]$$

$$\times [1.9\sqrt{4,000}$$

$$+ (2,500)(0.0025)(30,630)(90)/1,106,179]$$

$$= 0.85(2.5)(135.7) = 288.5 \text{ psi}$$

<u>Step 13a</u>. Determine the thickness of concrete required to carry the shear.

$V_u = 30,630$ lb/in

$v_c = 288.5$ psi

$d = 30,630/288.5 = 106.2$ inches

<u>Step 14a</u>. Determine the amount of flexural reinforcement required.

Main reinforcement:

Assume "a" block = 6 inches

$$A_s = \frac{M_u b}{f_s(d - a/2)}$$

$M_u = 1,478,660$ in-lb/in

$b = 12$ inches

$d = 106.2$ inches

$a =$ assumed value of 6 inches

$f_s = 60,000$ psi

$$A_s = \frac{(1,478,660)(12)}{(60,000)(106.2 - 6/2)}$$

$$= 2.87 \text{ in}^2/\text{ft}$$

$a = (A_s f_s)/0.85bf'_c$

$f'_c = 4,000$ psi

$$a = \frac{(2.87)(60,000)}{(0.85)(12)(4,000)} = 4.22 \text{ inches}$$

$$A_s = \frac{(1,478,660)(12)}{(60,000)(106.2 - 4.22/2)}$$

$$= 2.84 \text{ in}^2/\text{ft}$$

$$A_{min} = 0.0025bd$$

$$= 0.0025(12)(106.2)$$

$$= 3.19 \text{ in}^2/\text{ft}$$

Use minimum steel: $A_s = 3.19$ in^2/ft

Area of #11 bar = 1.56 in^2

Use two #11 bars, top and bottom, at 12-inch spacing. These bars should extend from one end of the foundation to the other end (see Figure C.13).

Reinforcement in other direction:

$$A_s = 0.001bT_c$$

$$T_c = 110 \text{ inches}$$

$$A_s = 0.001(12)(110) = 1.32 \text{ in}^2/\text{ft}$$

Use one #10 top and bottom at 12-inch spacing. These bars should be placed in both extensions of the foundation (see Figure C.13).

Step 15a. Determine the actual thickness of the foundation.

$$d = 106.2 \text{ inches}$$

$$d_b = 1.41 \text{ inches}$$

$$c = 3.0 \text{ inches}$$

$$T_c = 106.2 + 1.41/2 + 3.0 = 109.9 \text{ inches}$$

Use $T_c = 110$ inches

C.6 Example C.2: Single Cell Barrier with Buttress Walls

Example C.2: Design the foundation extension of a single cell barrier with buttress walls. This problem is based on the actual design of the structure shown in Figures C.16 through C.18.

Required: Determine the length, thickness and amount of reinforcing steel required for the foundation extension of a single cell barrier.

Step 1. Given:

a. Configuration of the structure and details of the backwall element which is designed to the incipient failure condition (see Figures C.16 through C.18).

b. Quantity of explosives: six charges located within the cell as shown in Figures C.16 and C.17. The weights of the charges are:

W_1 and W_2 = 54 lbs each

W_3 and W_4 = 146 lbs each

W_5 and W_6 = 146 lbs each

All charges are TNT.

c. Soil data available:

The soil at the construction site is a medium sand. In this problem, extensive test data are available to more accurately determine the properties of the soil for use in the analysis. The test data are omitted here for brevity and the properties are supplied in the subsequent computations as needed.

d. Design strength for building materials:

1. Concrete f'_c = 4,000 psi

2. Steel f_y = 60,000 psi

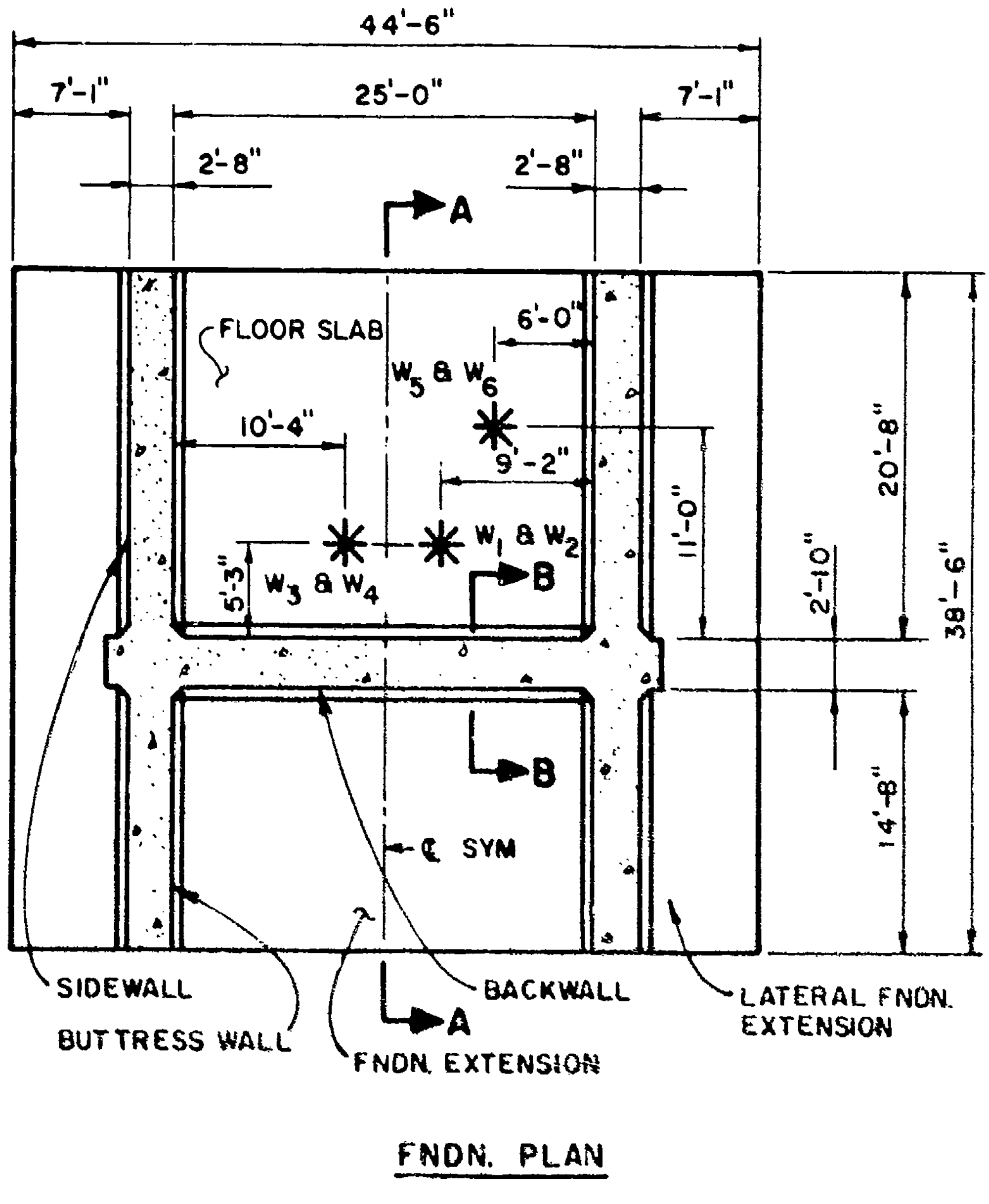


Figure C.16 Example C.2: Dimensions of structure and charge locations - Plan view.

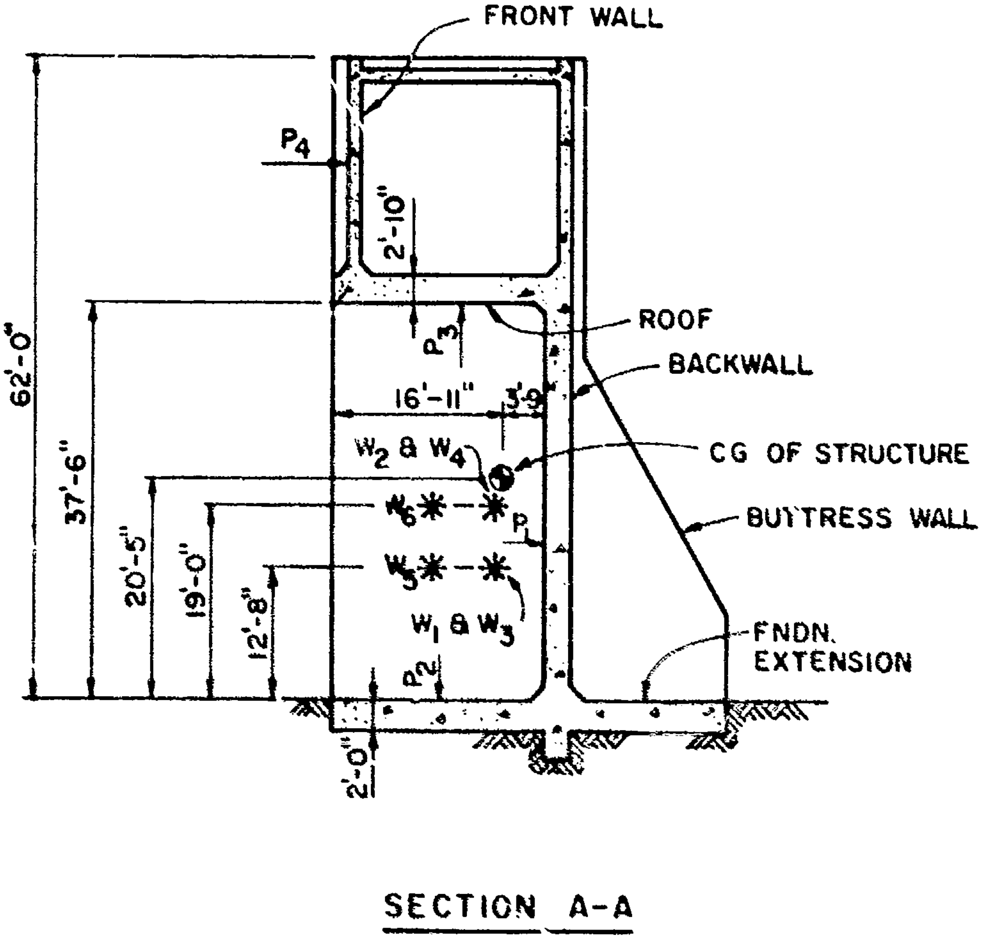


Figure C.17 Example C.2: Dimensions of structure and charge locations - Section.

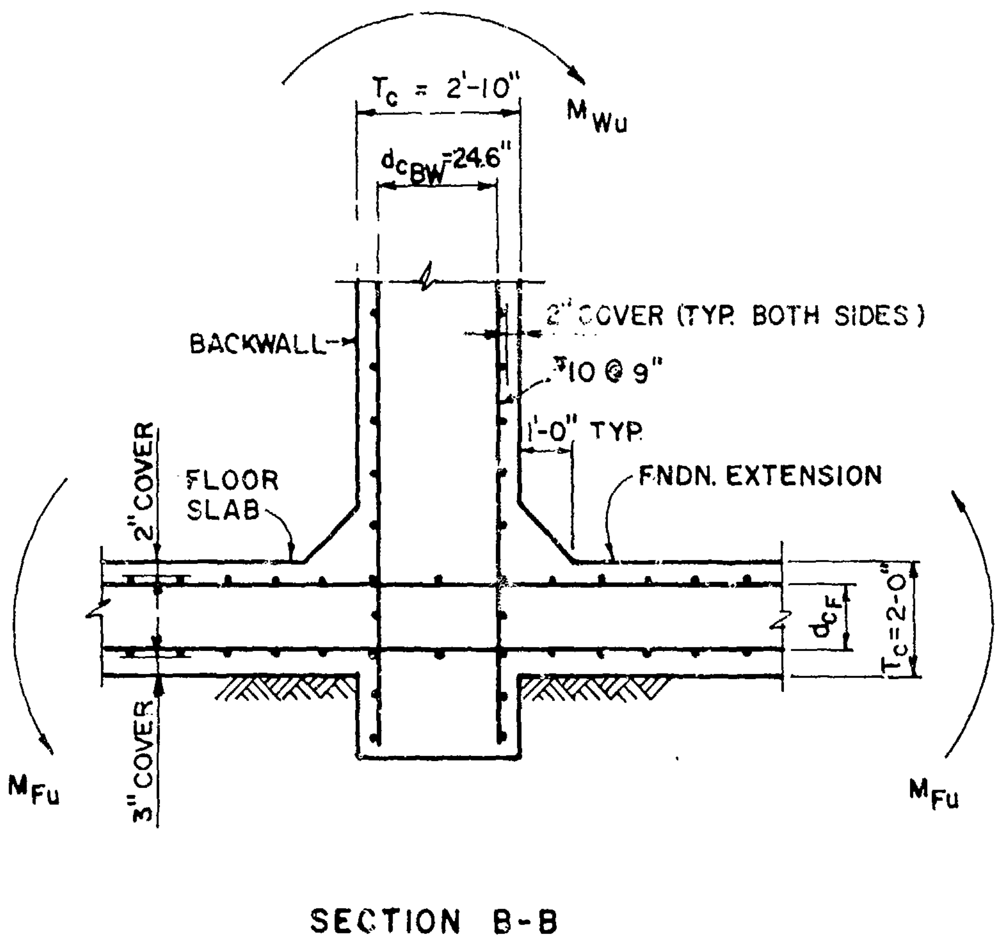


Figure C.18 Example C.2: Details of backwall and floor slab.

Step 2. Estimate the dimensions of the foundation extension to be used in the analysis. In addition, determine for the foundation, the area of reinforcing steel required to develop the strength of the backwall.

In this problem, the guidelines of Section C.2.2 were not utilized. The thickness of the foundation chosen is 24 inches.

The computation of the area of reinforcement required for the foundation to develop the backwall is given below:

Assume #9 bars (bar diameter = 1.13 inches, bar cross-sectional area = 1.00 in^2) required for foundation to develop strength of backwall and sidewalls.

$$d_{c_F} = 24 - 3 - 2 - 2(1.13) - 1.13$$
$$= 15.61 \text{ inches}$$

$$M_{Fu} = M_{Wu}/2$$

Cross-sectional area of #10 bar = 1.27 in^2

$$A_{s_F} d_{c_F} = A_{s_{BW}} d_{c_{BW}}/2$$

$$A_{s_F} = (1.27)(24.6)/(2)(15.61)$$
$$= 1.0 \text{ in}^2 = \text{Area of \#9 bar}$$

Use #9 bars at 9-inch spacing.

Step 3. Determine the soil bearing pressure for the weight of the structure.

The weight of the structure is 2.96 x 10^6 lbs. The weight computations are omitted for brevity.

The allowable bearing pressure for the soil is 1.25 tons/ft^2.

The area of the foundation in contact with the soil is:

$A = (44.5)(38.5) = 1{,}713.3 \text{ ft}^2$

$$\text{Bearing pressure} = \frac{2{,}960{,}000}{2{,}000(1{,}713.3)}$$

$$= 0.85 \text{ T/ft}^2 < 1.25 \text{ T/ft}^2$$

The foundation is adequate for the dead and live load condition.

<u>Step 4</u>. Determine the average impulse loads on the floor slab within the cell.

Design charge weights:

W_1 and W_2 = 1.20(54) = 65 lbs

W_3 thru W_6 = 1.20(146) = 175 lbs

The impulse loads on the floor slab are computed using the computer program of Reference 2. The computed impulse loads are listed below:

W_1: $\bar{i}_b$ = 449 psi-ms

W_2: $\bar{i}_b$ = 408 psi-ms

W_3: $\bar{i}_b$ = 916 psi-ms

W_4: $\bar{i}_b$ = 766 psi-ms

W_5: $\bar{i}_b$ = 873 psi-ms

W_6: $\bar{i}_b$ = 744 psi-ms

Since the configuration of the structure is unusual, the arrival times and load durations must be computed by hand using the method and the data presented in Appendix B. The computations are omitted for brevity. The quantities computed are included in the input data deck for this problem, which is presented in Appendix D.

<u>Step 5</u>. Establish the soil properties to be used in the analysis. As discussed previously, a large quantity of test data is available to determine the properties of the soil. The properties derived from the data are listed on the following page.

Description: medium sand

Modulus of Elasticity: 5,600 psi

Poisson's Ratio: 0.33

Friction Factor: 0.70

The structure is analyzed for these soil properties only.

Step 6. Prepare the input data deck for the computer program. Since the configuration of the structure is unusual, the "General Structure" and "Special Loading Options" must be utilized to analyze the structure (see Section 5). The input data deck is presented in Appendix D.

Step 7. Run the analysis on the CDC 6600 computer using the overturning analysis program.

Step 8. Inspect the results of the analysis. A portion of the printed output of the analysis is presented in Appendix D.

A summary of the peak response parameters for the structure is presented below:

Maximum rotation of structure	= 1.58°
Maximum horizontal displacement of foundation	= 6.34 inches
Ratio of maximum rotation to overturning angle	= 0.04

Inspection of the above tabulation of the results indicates that the structure:

a. Has reached its peak response

b. Did not overturn

c. Did not experience excessive horizontal displacements.

Therefore, the design proceeds to the next step.

Step 9. The peak rotation of the structure is 4 percent of the overturning angle, whereas rotations to incipient overturning (approximately 40 degrees) could be tolerated. The bearing pressure, computed for the dead load condition, is approximately 70 percent of the allowable bearing pressure for the soil. Based on these figures, the plan size of the foundation could be reduced to approximately 30 percent. However, this particular structure contains massive steel vessels which are used in the manufacture of the explosive. The vessels are supported by an equally massive steel framework. At the time this structure was designed, the size and weight of the vessels were unknown. The estimated weight of these items was 500 tons; therefore, a generous margin was provided in the plan size of the foundation.

Therefore, no change in the plan size of the foundation is made.

Step 10b. Determine the design loading for the foundation extension.

The locations of the soil element attachment points on the foundation and the soil bearing pressure distributions at several time stations are shown in Figures C.19 and C.20. The computations of the applied loads on the portion of the foundation extension beyond the critical section for shear (approximately 20 inches from haunch) are presented below. The loads are computed for a 1-inch wide strip.

At t = 0.18586 second:

$$P_{cr} = \frac{(60.9 - 28.6)(21)}{(5)(33)} + 28.6$$

$$= 32.7 \text{ psi}$$

$$V_T = \frac{(32.7 + 60.9)[4(33) + 12]}{2}$$

$$= 6{,}739 \text{ lb/in}$$

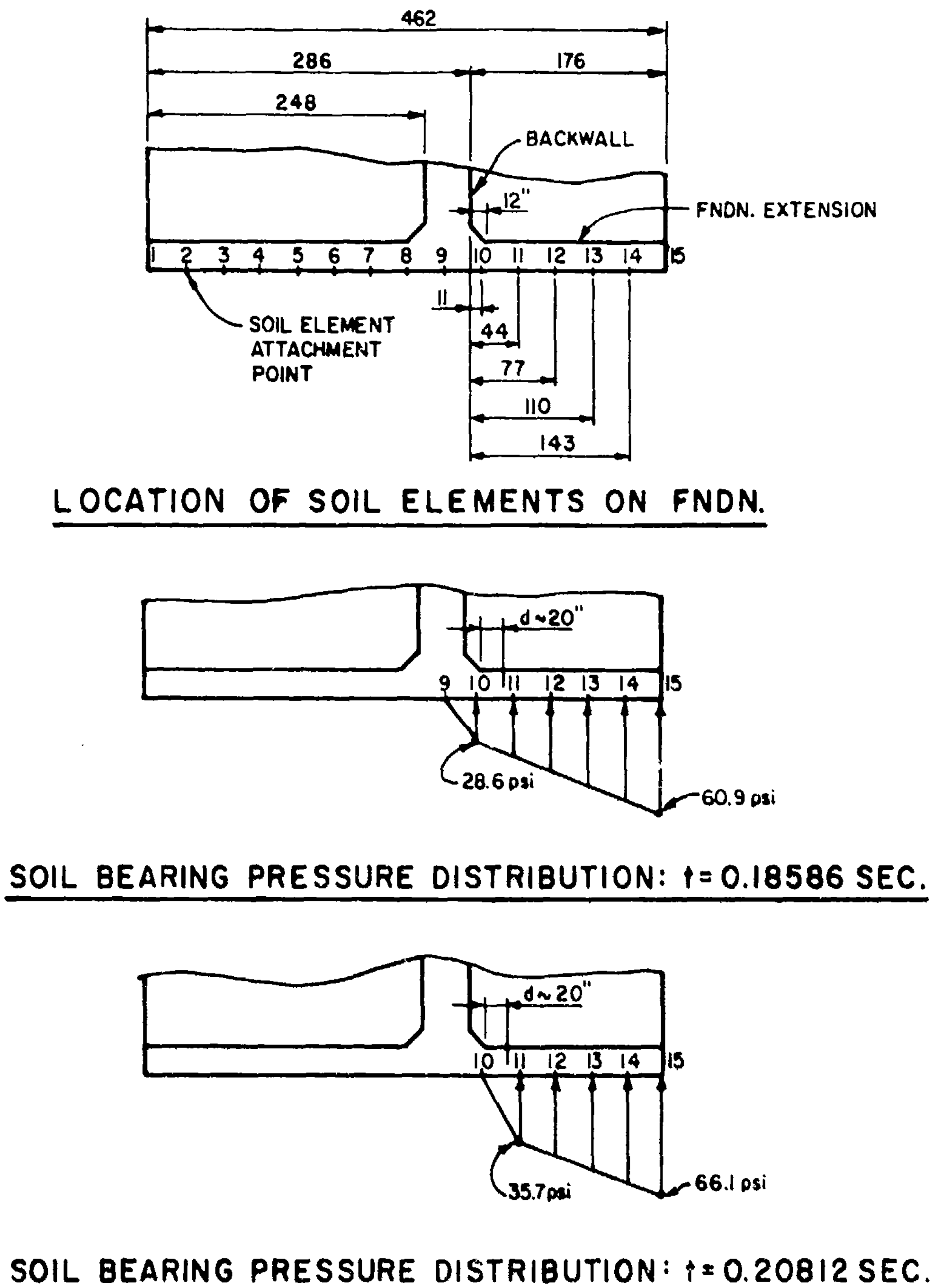
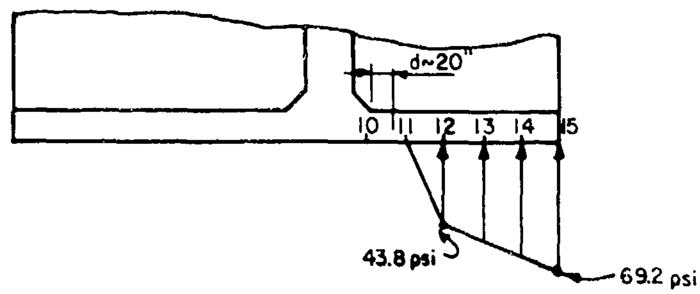
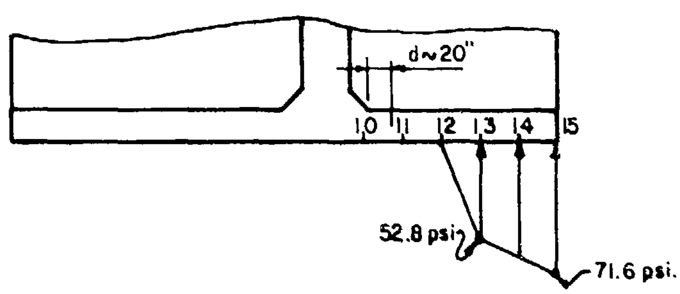


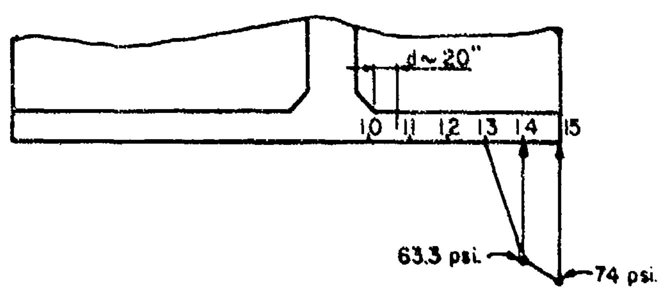
Figure C.19 Example C.2: Locations of soil elements on foundation and design loadings.



SOIL BEARING PRESSURE DISTRIBUTION: t= 0.22667 SEC.



SOIL BEARING PRESSURE DISTRIBUTION: t= 0.24893 SEC.



SOIL BEARING PRESSURE DISTRIBUTION: t= 0.29716 SEC.

Figure C.20 Example C.2: Design loadings.

at t = 0.20812 second:

$$P_{cr} = (21/33)(35.7) = 22.7 \text{ psi}$$

$$V_T = \frac{(22.7 + 35.7)(12) + (35.7 + 66.1)4(33)}{2}$$

$$= 7{,}069 \text{ lb/in}$$

at t = 0.22667 second:

$$V_T = (43.8)(33) + \frac{(43.8 + 69.2)3(33)}{2}$$

$$= 6{,}316 \text{ lb/in}$$

at t = 0.24893 second:

$$V_T = (52.8)(33) + \frac{(52.8 + 71.6)2(33)}{2}$$

$$= 4{,}976 \text{ lb/in}$$

at t = 0.29716 second:

$$V_T = (63.3)(33) + \frac{(63.3 + 74.1)(33)}{2}$$

$$= 3{,}312 \text{ lb/in}$$

The design load on the foundation extension is the soil bearing pressure distribution at t = 0.20812 second.

Step 11b. Establish the initial amount of flexural reinforcement for the foundation extension.

The nomenclature of Section 5-10 of Reference 1 is used to identify the various parameters of the problem. The parameters are defined as illustrated in Figure C.21.

The area of steel in the vertical direction (see Figure C.21) was initially determined in Step 2:

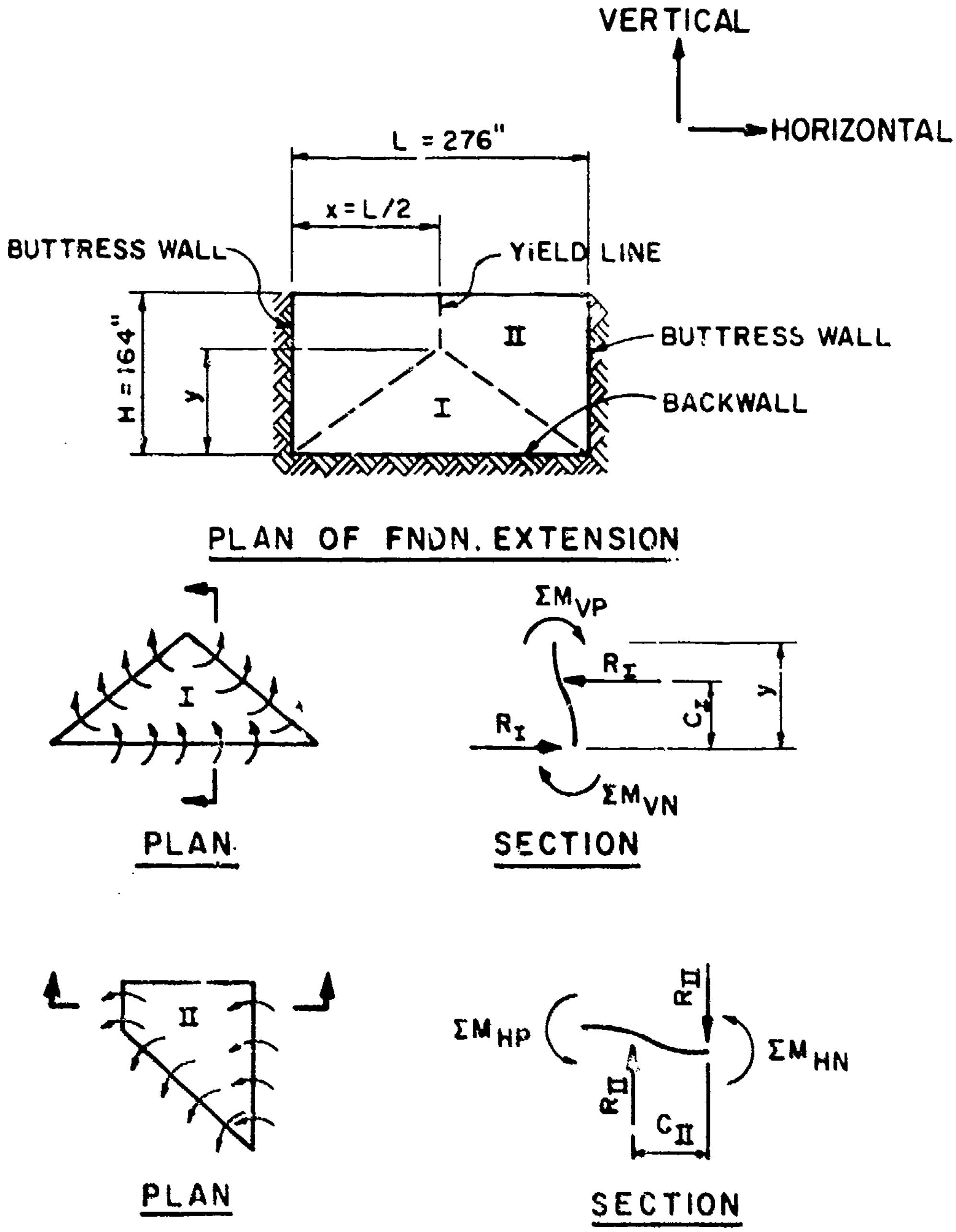


Figure C.21 Example C.2: Des!gn parameters, nomenclature and conventions.

#9 bar at 9-inch spacing: $A_{bv} = 1.0 \text{ in}^2$

$p_w = A_s/bd$

$A_s = 1.0(12)/9 = 1.33 \text{ in}^2/\text{ft}$

$b = 12$ inches

$d = 20$ inches

$p_{wV} = 1.33/(20)(12) = 0.0055 > 0.0025$

Since $p_{wV} > 0.0025$, use minimum steel in the horizontal direction.

$A_s = (0.0018)(20)(12) = 0.432 \text{ in}^2/\text{ft}$

$A_b = (0.432)(9/12) = 0.324 \text{ in}^2$

Begin the computations with #6 bars at 9-inch spacing in the horizontal direction.

$A_s = (0.44)(12/9) = 0.59 \text{ in}^2/\text{ft}$

Step 12b. Compute the ultimate positive and negative bending moment capacities in both directions using Equation (C.3).

Vertical direction:

Referring to Figure C.18:

$$d_{VN} = 24 - 3 - 0.75 - 1.128/2$$
$$= 19.7 \text{ inches}$$

$$d_{VP} = 24 - 2 - 0.75 - 1.128/2$$
$$= 20.7 \text{ inches}$$

$$a_V = A_s f_s / 0.85 f'_c b$$
$$= \frac{1.33(60{,}000)}{0.85(4{,}000)(12)} = 1.96 \text{ inches}$$

$$M_u = A_s f_s (d - a/2)/b$$

$$M_{VN} = \frac{(1.33)(60,000)(19.7 - 1.96/2)}{12}$$

$$= 124,500 \text{ in-lb/in}$$

$$M_{VP} = \frac{(1.33)(60,000)(20.7 - 1.96/2)}{12}$$

$$= 131,100 \text{ in-lb/in}$$

Horizontal direction:

$$d_{HN} = 24 - 3 - 0.375 = 20.6 \text{ inches}$$

$$d_{HP} = 24 - 2 - 0.375 = 21.6 \text{ inches}$$

$$a_H = \frac{0.59(60,000)}{0.85(4,000)(12)} = 0.87 \text{ inch}$$

$$M_{HN} = \frac{(0.59)(60,000)(20.6 - 0.87/2)}{12}$$

$$= 59,500 \text{ in-lb/in}$$

$$M_{HP} = \frac{(0.59)(60,000)(21.6 - 0.87/2)}{12}$$

$$= 62,400 \text{ in-lb/in}$$

Step 13b. Utilizing yield line theory, compute the ultimate resistance in bending of the foundation extension. The computation is performed for a trapezoidal loading having the same relative proportions as the design load. The computations are omitted here for brevity. The location of the yield line and the ultimate resistance are given below and defined as illustrated in Figure C.22 (Trial #1).

$$x = 119 \text{ inches}$$

$$p_u = 49 \text{ psi}$$

Step 14b. Compare the computed resistance (p_u) with the actual design load. For Trial #1, the computed resistance of 49 psi is less than the applied load of 66.1 psi. Therefore, the area of horizontal reinforcement is increased until the required resistance is achieved.

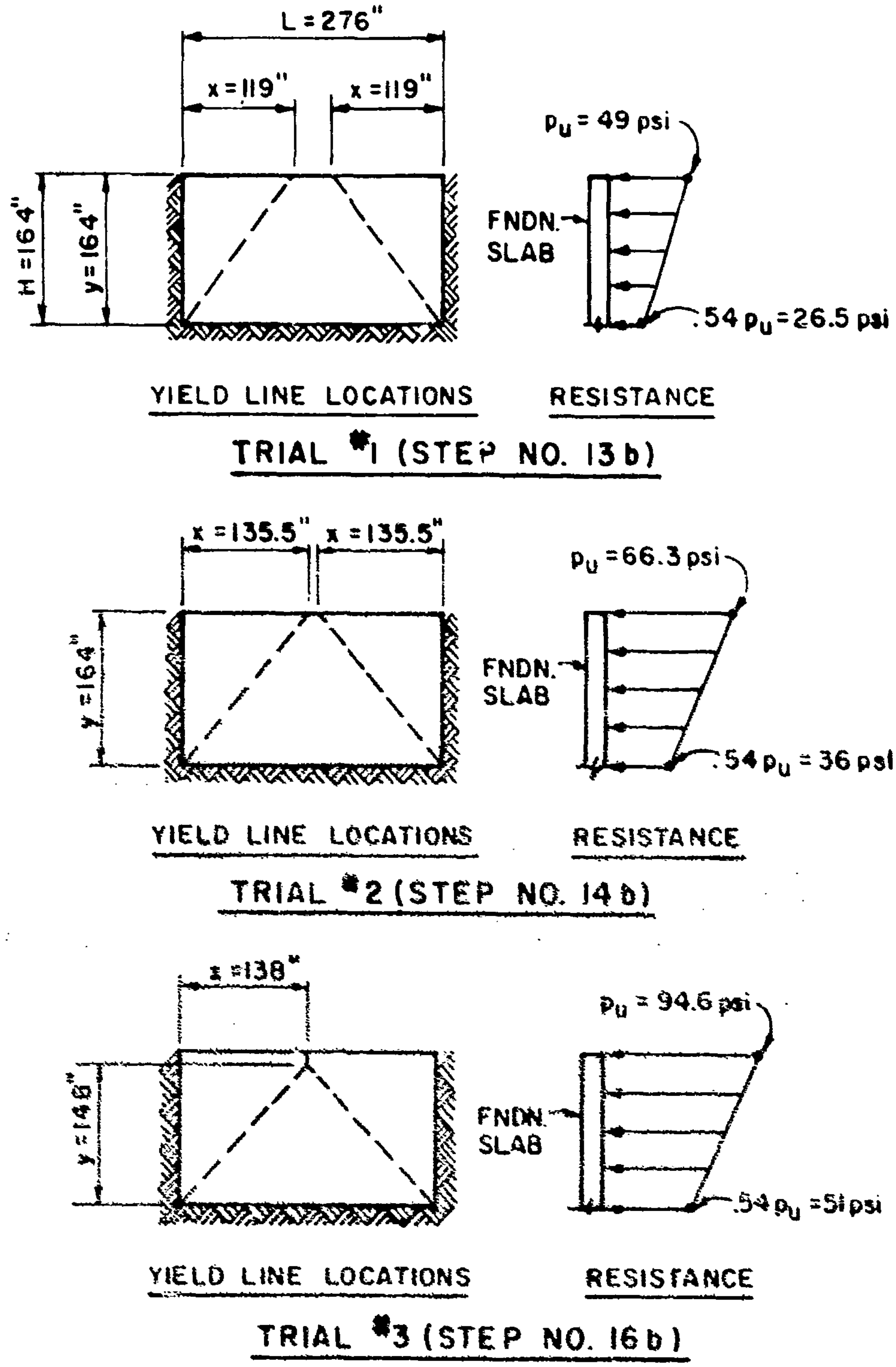


Figure C.22 Example C.2: Results of design computations - Yield line locations and ultimate resistance of foundation.

Trial #2 of #8 bars at 9-inch spacing in the horizontal direction yields the following results (see Figure C.22, Trial #2):

$x = 135.5$ inches

$p_u = 66.3$ psi > 66.1 psi

<u>Step 15b</u>. Based on the location of the yield lines determined in Step 14b, compute the shear stresses produced by the design load at the critical section for each sector of the foundation extension.

The shear stresses computed at the critical section for each sector are:

Sector I: $v_V = 180$ psi

Sector II: $v_H = 166$ psi

<u>Step 16b</u>. Compute the allowable shear stress for the concrete using Equation (C.2).

Vertical direction:

$$v_c = \phi(1.9\sqrt{f'_c} + 2{,}500p_w) \leq 2.28\phi\sqrt{f'_c}$$

$$= 0.85[1.9\sqrt{4{,}000} + 2{,}500(.0055)]$$

$$\leq 2.28(0.85)\sqrt{4{,}000}$$

$$= 114 \text{ psi} < 122.6 \text{ psi}$$

$$v_V = 180 \text{ psi} > 114 \text{ psi}$$

The thickness of concrete has to be substantially increased to carry the applied shear.

<u>Try $T_c = 38$ inches:</u>

Maintain same moment capacities:

Vertical direction:

$A_s = 1.33\ in^2/ft$

d_c(initial) $= 15.6$ inches for $T_c = 24$ inches

d_c(final) = 29.6 inches for T_c = 38 inches

$1.33(15.6) = A_s\ (29.6)$

$A_s = 0.7\ in^2/ft$

Use #7 bars at 9-inch spacing

$A_b = 0.6\ in^2$

$A_s = 0.8\ in^2/ft$

$d_V = 34$ inches

$p_w = 0.8/(12)(34) = 0.0020 < 0.0025$

Horizontal direction:

$p_{wH} = 0.0025$ since $p_{wV} = 0.0020 < 0.0025$

$d_H = 35$ inches

$A_s = (0.0025)(12)(35) = 1.05\ in^2/ft$

Use #8 bars at 9-inch spacing

$A_b = 0.79\ in^2$

$A_s = 1.05\ in^2/ft$

Recompute moment capacities:

Vertical direction:

$d_{VN} = 38 - 3 - 1.0 - 0.44 = 33.6$ inches

$d_{VP} = 34.6$ inches

$$a_V = \frac{0.8(60,000)}{0.85(4,000)(12)} = 1.18 \text{ inches}$$

$$M_{VN} = \frac{0.8(60,000)(33.6 - 1.18/2)}{12}$$

$$= 132,000 \text{ in-lb/in}$$

$$M_{VP} = \frac{0.8(60,000)(34.6 - 1.18/2)}{12}$$

$$= 136,000 \text{ in-lb/in}$$

Horizontal direction:

$d_{HN} = 38 - 3 - 0.5 = 34.5$ inches

$d_{HP} = 35.5$ inches

$$a_H = \frac{1.05(60,000)}{0.85(4,000)(12)} = 1.54 \text{ inches}$$

$$M_{HN} = \frac{1.05(60,000)(34.5 - 1.54/2)}{12}$$

$$= 177,000 \text{ in-lb/in}$$

$$M_{HP} = \frac{1.05(60,000)(35.5 - 1.54/2)}{12}$$

$$= 182,332 \text{ in-lb/lb}$$

Compute yield line location and ultimate resistance (see Figure C.22, Trial #3).

$y = 148$ inches

$p_u = 94.6 \text{ psi} > 66.1 \text{ psi}$

The shear stresses computed for each sector are:

Sector I: $v_V = 74$ psi

Sector II: $v_H = 98$ psi

The allowable shear stresses are:

Vertical: $v_c = 106$ psi

Horizontal: $v_c = 108$ psi

The applied shear stresses for both sectors are less than the allowable shear stresses for the concrete. Therefore, the design of this portion of the foundation extension is complete.

At this point, check the lateral extensions (see Figure C.16) of the foundation extension to insure that they can withstand an applied load of approximately two-thirds of the peak bearing pressure at the end of the extension.

The lateral extensions are designed in the same manner as the simple type foundation extension (see Section C.4.2). Since this procedure is illustrated in Example C.1, the computations are omitted from this problem.

Step 17b. Compute the load acting on the buttress wall.

The load on the buttress wall consists of the total applied load on Sector II of the interior portion of the foundation extension (see Figure C.2) plus the reactions of the lateral extensions.

Using this load, determine the thickness of concrete and the amount of reinforcing steel required for the buttress wall. The computations are omitted from this problem.

APPENDIX D

FORTRAN LISTING OF COMPUTER PROGRAM

D.1 General

This appendix contains the FORTRAN Listing of the Overturning Analysis Computer Program. Included also are two sample problems.

D.2 Computer Program

The computer program is written in FORTRAN IV. It can be run on the CDC 6600 computer using either the Extended (FTN) or the Regular FORTRAN compilers. A central memory field length of 150,000 words (octal) is required for compilation and execution of the program on the CDC 6600 computer.

The program consists of a main routine and ten subroutines. The operations performed by each are summarized below:

Main Routine BLASST - The main routine initiates the execution by calling Subroutine MULTB.

Subroutine MULTB - This subroutine reads in the title card, the problem specification card, the soil properties and the structure geometry. Using the structure geometry and the soil properties, the subroutine computes the elastic constants of the soil elements. Following this, the arrival times and load durations are computed (in the "Normal Option") by calling Subroutine ADTIM. If either the "Special Loading" or "General Structure Option" is used, the calling of this subroutine is bypassed and the arrival time and minimum load duration are read in instead. Next, a summary of the input parameters used in the analysis is printed out. If the response time of the backwall element is required, the subroutine reads in the design details of the backwall and calls Subroutine WALL which performs the desired computation. The problem solution proceeds with the calling of Subroutine CGTH2.

Subroutine ADTIM - This subroutine reads in the quantities and locations of the explosives and computes the arrival times and load durations on every loaded surface for each explosive charge. This subroutine is used in the "Normal Option" mode of the program only. The TNT data required for the computation are contained within the subroutine. Interpolation of this data is accomplished utilizing Function AR¯IM.

Function ARTIM - This function performs a geometric interpolation of the TNT data contained in Subroutine ADTIM.

Subroutine WALL - Subroutine WALL computes the maximum response time of the backwall element designed to either the incipient failure or the post failure fragment conditions. Four support condition options are considered:

1. One side fixed, three sides free.

2. Two adjacent sides fixed, two sides free.

3. Three sides fixed, one side free.

4. Four sides fixed.

Subroutine CGTH2 - This subroutine computes the following quantities in the "Normal Option" mode of the program:

1. Weight, mass and mass moment of inertia of structure.

2. Location of center of gravity of the structure.

3. Areas of all surfaces (perpendicular to the plane of motion of the structure) which are directly exposed to the blast.

4. Locations of the centroids of the loaded areas relative to the center of gravity of the structure.

5. Horizontal and vertical components of unit vectors normal to every loaded surface.

In the "General Structure Option", this computation is bypassed and the data listed above are read in on punched cards.

The next operation performed by this subroutine is the computation of the load history. In the "General Structure" and "Special Loading Options", the surface loading data (average impulse, arrival time and load duration) are read in on punched cards.

After the completion of the load-history computation, the load history is printed out and the program proceeds to the response computation by calling Subroutine GRMT2.

Subroutine GRMT2 - Subroutine GRMT2 computes the response of the structure to the applied loads. This involves computing the resisting forces in the soil and solving the equations of motion of the structure (see Section 2.2) to determine the accelerations, velocities and displacements of the structure. During the computation, several auxiliary subroutines are called to perform specialized calculations. These subroutines are:

1. Subroutine DEDE

2. Subroutine UPCHK

3. Subroutine R3

4. Subroutine FDN

After the numerical integration is completed, this subroutine prints out the response of the structure in the manner described in Section 6.

Subroutine DEDE - This subroutine monitors the displacement time history in each of the vertical soil elements to determine whether the element is in either the loading or unloading condition (see Section 4.2). When the element is in the loading condition, the subroutine computes the elastic resisting force in the element and the moment of the resisting force about the center of gravity of the structure.

Subroutine UPCHK - This subroutine computes the friction force acting on the foundation for the purpose of determining whether the foundation of the structure has separated from the soil.

Subroutine R3 - Subroutine R3 computes the moment of the horizontal resisting forces in the soil about the center of gravity of the structure.

Subroutine FDN - This subroutine computes the shear and corresponding bending moment at the critical section for shear on the foundation extension of a cantilever wall barrier. The bending moment at the face of the support is also computed. The computation is performed at every integration time station.

The following pages contain the FORTRAN Listing of the Overturning Analysis Program for the CDC 6600 computer.

```
                          NHVFACN    RUN V2.3  F58 180   09/26/75  17.52.39

              PROGRAM BLASST(INPUT,OUTPUT,TAPE2=INPUT,TAPE5=OUTPUT)
000003        COMMON CN, NF, TWOT, IOTC,IC1,IC2,CWSW, ICTHE,RESC(15),NWALL,
             1      IOT,N,NS,E1,E2,SHIP,INEL,INEU,BTAX,BTAY,MW,EO,CL,HS,TS,TW,
             $IT,IBBR,TJ,TASW  ,DELTW,NUMIW,                 UVEC(15,2),
             $IFACE(15),     IT,HS,WAL,NUMPT,RTIME,BLANK(6) ,FOP,
             $            LOTWN,ICAL,KOEL2,AMUMP,TT(20,5,2),             DATA(20,?
             $1,      DZ,PV,AW,X,Y,PDS,EBLPC,WU,WUP,AI,TWALL,PIB,D,WE,VE,NVIL
000003        COMMON       VF,NFOW,WALNM,NLOAD
000003        IT=1
000004        CALL MULTW
000005        CALL EXIT
000004        END
```

```
              SUBROUTINE MCLIP
000002        COMMON CS, FF, TMCT, IOTC,IC1,IC2,CASW, ITITF,XDESC(15),NWALL,
             *       IOT,N,NS,F1,F2,SPTP,XMEL,XMEL,WTAV,FTAV,PW,DE,CL,BS,TS,TW,
             *T(1,1C33),TJ,TASM  ,DELTM,NUMTM,                UVECT(5,2),
             *AFACE(5),        T2,HS,DAL,NUMPT,XTIME        ,         WT,AM(1),
             *RLANX(2) ,X2F,LUTRN,ICA1,NCEL2,ANUMP,TT(20,5,2),          DATA(20
             *,7),       DE,FV,PH,Y,Y,FOS,XMLMU,BU,BUP,X1,TWALL,XIB,B,WK,WE,NVEL
000002        COMMON      JF,NFDN,MALNM,NLCAD
000032        LPTUN=0
000003        IOTC = 0
000004        IOT = 0
000005        IOTNE = 0
000006        IZ=0
       C      ****************************************************************
       C      READ STRUCTURE DESCRIPTION CARD-CARD TYPE 1
       C      ****************************************************************
000007        READ(2,1) KDATC
000014      1 FORMAT(15A8)
000014     52 FORMAT( 1H1,25X,15A8//)
       C      ****************************************************************
       C      READ PROBLEM SPECIFICATION CARD-CARD TYPE 2
       C      ****************************************************************
000014        READ(2,2)NP,N,NS,NUMTM,     IC2,ICA1,NCEL2,NUMPT,NWALL,NVEL,NFDN,
             1 NLCAD
000050        IF(NP)1032,1032,105
000052    105 WRITE (5,52)KDATC
       C      ****************************************************************
       C      PRINT SUMMARY OF INPUT PARAMETERS
       C      ****************************************************************
000067        WRITE(5,11)NP,N, NS, NUMTM
000074        GO TO 923
000075      2 FORMAT(8I5,5X,I115)
000075     11 FORMAT(25X,17HNUMBER OF CHARGES,6X,I5,/,25X,15HNUMBER OF WALLS,50
             1X,I5,/,25X,22HNUMBER OF SOIL SPRINGS,43X,I5,/,25X,24HNUMBER OF TIM
             2E INCREMENTS,37X,I5)
000075   1032 WRITE(5,2030)
000121   2030 FORMAT(////1X,26HPROBLEM SOLUTION COMPLETED/////)
000121        CALL EXIT
       C      ****************************************************************
       C      READ SOIL PROPERTIES CARD-CARD TYPE 3
       C      ****************************************************************
000152    923 READ (2,3) C1, FF, SPTP, XMEL, XMEL, CTAV, CTAV
       C      ****************************************************************
       C      READ STRUCTURE GEOMETRY CARD-CARD TYPE 4
       C      ****************************************************************
000124        READ (2,3) TW, TS,        CL, HW, XBB, HW,WBTAM
000144        FF = HW / HT
000152        BS = BW + 3.0
000152        GO TO(120,250,120,300),N
000162    120 B= CL*12.0
000164        GO TO 400
000164    250 B= CL*12.0  +TW
000170        GO TO 400
000171    300 B= CL*12.0  + 2.0*TW
```

```
      [illegible]                       [illegible]   RUN V2.1  PSR 100   09/26/75  17.52.39
[illegible]     600 [illegible]                                                        0067
          C     ****************************************************************       0068
          C     COMPUTE TOTAL SPRING CONSTANTS FOR SOIL AND INDIVIDUAL SPRING           0069
          C     CONSTANTS FOR SOIL ELEMENTS                                            0070
          C     ****************************************************************       0071
[illegible]         [illegible]                                                        0072
[illegible]         [illegible]                                                        0073
[illegible]         [illegible]                                                        0074
[illegible]         [illegible]                                                        0075
[illegible]         [illegible]                                                        0076
[illegible]         [illegible]                                                        0077
[illegible]         [illegible]                                                        0078
[illegible]         [illegible]                                                        0079
[illegible]         [illegible]                                                        0080
[illegible]         [illegible]                                                        0081
[illegible]         [illegible]                                                        0082
[illegible]         [illegible]                                                        0083
          C     ****************************************************************       0084
          C     [illegible] TIME STEP DATA CARD-CARD TYPE [illegible] GENERAL STRUCTURE OR 0085
          C     [illegible] LOADING OPTIONS                                            0086
          C     ****************************************************************       0087
[illegible]     [illegible]                                                            0088
[illegible]         [illegible]                                                        0089
[illegible]     [illegible]                                                            0090
[illegible]         [illegible]                                                        0091
          C     ****************************************************************       0092
          C     CALL SUBROUTINE [illegible] TO COMPUTE ARRIVAL AND DURATION TIMES FOR  0093
          C     NORMAL [illegible]                                                     0094
          C     ****************************************************************       0095
[illegible]         [illegible]                                                        0096
[illegible]         CALL [illegible]                                                   0097
[illegible]         [illegible]                                                        0098
[illegible]     [illegible]                                                            0099
[illegible]     [illegible]                                                            0100
[illegible]     [illegible]                                                            0101
[illegible]     [illegible] CONTINUE                                                   0102
[illegible]     [illegible] WRITE([illegible])                                          0103
[illegible]     [illegible] FORMAT([illegible] TIME OF ARRIVAL OF [illegible] TO NEAREST [illegible] 0104
               [illegible] DURATION TIME [illegible]                                   0105
               [illegible]                                                             0106
[illegible]         [illegible]                                                        0107
[illegible]         [illegible]                                                        0108
[illegible]         [illegible]                                                        0109
[illegible]     [illegible]                                                            0110
[illegible]         [illegible]                                                        0111
[illegible]     [illegible] WRITE([illegible])                                         0112
[illegible]     [illegible] FORMAT([illegible] TIME [illegible] INTERNAL [illegible]   0113
               [illegible] TIME INTERNAL [illegible]                                   0114
[illegible]         [illegible]                                                        0115
          C     ****************************************************************       0116
          C     PRINT ELASTIC PROPERTIES AND SPRING CONSTANTS FOR [illegible]          0117
          C     ****************************************************************       0118
[illegible]    [illegible] WRITE([illegible])                                          0119
[illegible]         GO TO [illegible]                                                  0120
[illegible]    [illegible] WRITE([illegible])                                          0121
```

```
            MULTO                    NMXFACN     RUN V2.3  PSR 390    09/26/75  17.52.39

000631    1050 WRITE(6,10)XKH1,XKV1,XKH2,XKV2
000615         WRITE(6,15)XK1,YK1,XK2,YK2
000631       1 FORMAT (4F10.3)
000631       5 FORMAT(25X,15HSOIL PROPERTIES,/,25X,15H---------------,/,25X,29HMO
            1DULUS OF ELASTICITY E1(PSI),31X,F10.2,/,25X,29HMODULUS OF ELASTICI
            2TY E2(PSI),31X,F10.2,/,25X,43HNORMAL STRESS AT WHICH MODULUS CHANG
            3ES(PSI),17X,F10.2,/,25X,23HCOEFFICIENT OF FRICTION,37X,F10.2,/,25X
            4,16HPOISSONS RATIO,44X,F10.2,/,25X,15HSHAPE FACTOR BX,45X,F10.2,/,
            525X,15HSHAPE FACTOR BY,45X,F10.2)
000631      55 FORMAT(25X,15HSOIL PROPERTIES,/,25X,15H---------------,/,25X,29HMO
            1DULUS OF ELASTICITY E1(PSI),31X,F10.2,/,25X,29HMODULUS OF ELASTICI
            2TY E2(PSI),31X,F10.2,/,25X,43HNORMAL STRESS AT WHICH MODULUS CHANG
            3ES(PSI),17X,F10.2,/,25X,23HADHESION CONSTANT(PSF) ,37X,F10.2,/,25X
            4,16HPOISSONS RATIO,44X,F10.2,/,25X,15HSHAPE FACTOR BX,45X,F10.2,/,
            525X,15HSHAPE FACTOR BY,45X,F10.2)
000631      10 FORMAT(25X,17HKH1/SPRING(LB/IN),30X,F15.2,/,
           1      25X,17HKV1/SPRING(LB/IN),30X,F15.2,/,
           2      25X,17HKH2/SPRING(LB/IN),30X,F15.2,/,
           3      25X,17HKV2/SPRING(LB/IN),30X,F15.2)
000631      15 FORMAT(25X,18HKH1 TOTAL(LB/IN),30X,F15.2,/,
           1       25X,18HKV1 TOTAL(LB/IN),30X,F15.2,/,
           2       25X,18HKH2 TOTAL(LB/IN),30X,F15.2,/,
           3       25X,18HKV2 TOTAL(LB/IN),30X,F15.2//)
000631         TWPT = TW
000637     310 FORMAT(4F10.0,2F5.0,3F10.3)
000637         IF(NWBP)1450,550,550
         C     ****************************************************************
         C     READ BACK WALL STRUCTURAL DETAILS CARD-LARC TYPE FICTIONAL)
         C     ****************************************************************
000636     550 READ(2,310)EI10,CC,DI,PH,A,Y,FCS,DELMU,WF
         C     ****************************************************************
         C     CALL SUBROUTINE WALL TO COMPUTE PEAK RESPONSE TIME FOR BACKWALL
         C     ****************************************************************
000642         CALL        WALL      (CL,WW,WF,TWALL,W,CC,FV,PH,A,Y,FCS,DELMU,EI0,
              1DM,PCP,TI,XP)
000702     450 CALL EXIT
000724         RETURN
000645         END
```

```
NAVFACW     RUN V2.3  PSR 380   09/20/79  17.52.39

      SUBROUTINE ADTI[illegible](TASM,TCLG,J)
      DIMENSION TAPT(6), ZZ(30),TTA(30),TTO(30),TC(3),TOPT(6),Z(6),B(6)
      DIMENSION B1(1)
      COMMON CS, HF, [illegible], IOTC,IC1,IC2,CBSW, [illegible]
     1      IOT,N,NS,F1,F2,[illegible]
     [illegible]
     [illegible]
     [illegible]
      DATA ZZ/0.10,0.20,0.25,[illegible]
     1 2.0,2.5,[illegible],10.0,14.0,16.5,20.0,25.0,
     2 30.0,[illegible],50.0/
      DATA TTO/[illegible]
     1 [illegible]
     2 [illegible]
      DATA TTA/[illegible]
     1 [illegible]
     2 [illegible]
C     ****************************************************************
C     READ CHANGE DATA CARD-CARD TYPE 7-FOR NORMAL OPTION ONLY
C     ****************************************************************
      READ(2,[illegible])
    1 FORMAT([illegible])
      [illegible]
      [illegible]
      DO 1 [illegible]
    1 [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
C     ****************************************************************
C     COMPUTE TIME OF ARRIVAL OF [illegible]
C     ****************************************************************
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
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      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
```

```
C     ******************************************************************
C     COMPUTE AVERAGE ARRIVAL AND LOAD DURATION TIMES FOR BACKWALL
C     ******************************************************************
[illegible]
C     ******************************************************************
C     COMPUTE TIME OF ARRIVAL OF BLAST ON FLOOR AND ROOF
C     ******************************************************************
[illegible]
C     ******************************************************************
C     COMPUTE AVERAGE ARRIVAL AND LOAD DURATION TIMES FOR FLOOR AND ROOF
C     ******************************************************************
[illegible]
```

```
[illegible]
[illegible] GO TO ([illegible]100,110,120,[illegible])
[illegible]
[illegible]
[illegible]
      GO TO 3
100   RETURN
      END
```

```
                 FUNCTION ARTIM(ZZ,TTA,Z,NSIG)
000007           DIMENSION ZZ(30),TTA(30)
           C     ***************************************************************
           C     INTERPOLATE TO FIND ARTIM FOR GIVEN Z ON CURVE OF TTA VS. ZZ
           C     ***************************************************************
000007           IF (Z-ZZ(1)) 11,12, 12
000011        11 GO TO(110,120),NSIG
000017       110 ARTIM=0.0
000020           GO TO 15
000021       120 ARTIM=TTA(1)
000022           GO TO 15
000023        12 DO 13 I=2,30
000025           IF (Z-ZZ(I)) 14,14,13
000030        13 CONTINUE
000032           GO TO 15
000033        14 B=ZZ(I+1)-ZZ(I)
000036           A=TTA(I+1)-TTA(I)
000040           BB=Z-ZZ(I)
000042           AA=BB*A/B
000044           ARTIM=TTA(I)+AA
000050        15 RETURN
000052           END
```

```
              SUBROUTINE WALL     (C1,H1,WP,TM,N,DC,PV,PH,X,Y,FOS,XKLPU,XI,RU,
             1 RUP,X1,VF)
000024        CL=C1*12.0
000025        HW=H1*12.0
000026        XKLMP=.66
000030        TANA=.21256
000031        XMH=PH*(DC**2.0)*FDS
000037        XMV=PV*(DC**2.0)*FDS
        C     ****************************************************************
        C     COMPUTE PEAK RESPONSE TIME OF BACK WALL ELEMENT FOR SUPPORT
              CONDITIONS LISTED IN SUBROUTINE
        C     ****************************************************************
000046        GO TO(20,50,80,120),N
        C     ****************************************************************
        C          1. ONE SIDE FIXED, THREE SIDES FREE
        C     ****************************************************************
000054     20 RU=2.0*XMV/(HW**2.0)
000061        TM=XI/RU
000064        IF(VF)200,200,30
000066     30 TM=TM-225.*DC*XKLMP*VF/RU
000074        GO TO 200
        C     ****************************************************************
        C          2. TWO SIDES FIXED, TWO SIDES FREE
        C     ****************************************************************
000074     50 IF(X)60,60,70
000076     60 RU=10.0*XMH/(Y**2.)
000104        GO TO 75
000105     70 RU=10.0*XMH/(Y**2.)
000113        GO TO 78
000114     75 IF(Y-CL)76,76,77
000117     76 RUP=2.0*XMH/(CL**2.)
000124        X1=Y*TANA
000130        GO TO 150
000131     77 RUP=2.0*XMV/(HW**2.)
000136        X1=CL*TANA
000141        GO TO 150
000142     78 IF(Y-HW)79,79,74
000145     79 RUP=2.0*XMV/(HW**2.0)
000152        X1=Y*TANA
000154        GO TO 150
000157     74 RUP=2.0*XMH/(CL**2.)
000164        X1=HW*TANA
000167        GO TO 150
        C     ****************************************************************
        C          3. THREE SIDES FIXED, ONE SIDE FREE
        C     ****************************************************************
000170     80 IF(X)90,90,100
000172     90 RU=10.0*XMV/(Y**2.0)
000177        RUP=16.0*XMH/(CL**2.)
000204        X1=Y*TANA
000211        GO TO 150
000212    100 RU=10.0*XMH/(Y**2.)
000217        IF(Y-HW)105,155,110
000223    105 RUP=2.0*XMV/(HW**2.)
```

```
           WALL                    NMVFADN    RUN V2.3  PSR 330   09/26/75  17.52.19

000230           X1=X*TANA
000234           GO TO 150
000237       110 RUF=16.0*HV/(CL**2.)
000242           X1=HM*TANA
000245           GO TO 150
            C    ***********************************************************
            C         4. FOUR SIDES FIXED
            C    ***********************************************************
000246       120 IF(Y)130,130,140
000250       130 RU=10.0*EPV/(Y**2.)
000255           IF(Y-.5*CL)131,132,135
000262       131 RUF=16.0*HMV/(CL**2.)
000267           X1=Y*TANA
000273           GO TO 150
000274       135 RUF=16.0*EPV/(HM**2.)
000301           X1=.5*CL*TANA
000305           GO TO 150
000314       140 RU=10.0*EPW/(X**2.)
000313           IF(X-.5*HM)141,142,145
000320       141 RUF=16.0*HPV/(HM**2.)
000325           X1=X*TANA
000331           GO TO 150
000332       145 RUF=16.0*EPV/(CL**2.)
000337           X1=.5*HM*TANA
000343       150 [illegible]
000344           [illegible]
000346           [illegible]
000350           [illegible]
000357           [illegible]
000365           [illegible]
000401           TH=TH -[illegible]
000405       200 TH=TH/1833.3
000407           RETURN
000407           END
```

```
                 SUBROUTINE CGTH2
000002           DIMENSION XCORD(5), YCORD(5)
000002           COMMON C9, NF, TWOT, IOTC,IC1,IC2,CPSH, IOTNE,KDESC(35),NWALL,
                $        IOT,N,NS,E1,E2,SHTP,XMEU,XNEU,BTAX,BTAY,HW,BB,CL,BS,TS,TW,
                $F(3,1000),TJ,TASH   ,DELTM,NUMTP,                 UVECT(5,2),
                $AFACE(5),       IZ,HS,TKP,NUMPT,KTIME,                     WT,AH(3),
                $ YB, XP,              XBP,LATRN,ICA1,INK,BLIN,TT(20,5,2),DATA(20,7)
000002           COMMON  DC,PV,PH,X,Y,FOS,XKLMU,RU,RUP,X1,TWALL,XTB,B,HK,VK,NVEL
000002           COMMON        VF,KFON,HAUNH,NLOAD
000002           IF(IZ-10  ) 1,10,10
000005         1 IZ = IZ +1
000007           IF(IZ-1) 3,3,1000
000010         3 SBB=BS/BB
000012           HB=HW/BB
          C      ****************************************  **************************
          C      PRINT STRUCTURAL GEOMETRY
          C      **********************************************************************
000014           WRITE(5,1200)TW,C9,CL,HW,SBB,HB
000033           CL = CL *12.
000035           HW =HW *12.
000036           BP=BB*12.0
000037           BS=BS 12.0
000040           TS = TW *C9
000042           C4 = TW / BB
          C      **********************************************************************
          C      DETERMINE HORIZONTAL AND VERTICAL COMPONENTS OF UNIT VECTORS
          C      NORMAL TO LOADED SURFACES OF STRUCTURE-FOR NORMAL OPTION ONLY
          C      **********************************************************************
000043           UVECT(1,1) = 1.
000045           UVECT(1,2) = 0.
000045           UVECT(2,1)=0.
000047           UVECT(2,2)=1.
000050           UVECT(3,1)= 0.
000051           UVECT(3,2)= -1.
000052           AFACE(1) = HW*CL
000054           AFACE(2) = BS*CL
000055           AFACE(3)=BS*CL
000056           GO TO 6
000057      1000 WRITE(5,1100) KDESC
000065           C4=TW/BB
000067           C9=TS/TW
000071           SBB=BS/C9
000072           HB=HW/BB
000074           WRITE(5,1200)TW,C9,CL,HW SBB,HB
000113         6 WRITE(5,1700)BB,BS,TS,C4
000127           IF( IOT) 6, 11, 6
000131         6  IF(ICS) 11,11, 10
000132        10 CALL WALTB
000133        11 DO 12 I =1,3
000135           DO 12 J=1,1000
000136        12 F(I,J)=0.0
000144           IF(ICA1)41,41,42
000146        42 IF(LOTT ) 45,45,41
          C      *************************   ***************************************
```

```
          C     READ MASS DATA CARD-CARD TYPE 8-FOR GENERAL STRUCTURE OPTION
          C     ****************************************************************
000150       45 READ(2,430)WT,AM(3),XR,YB,XP
00016F          AM(1)=WT/386.0
000170          AM(2)=AM(1)
000171          WRITE(5,500)XB,YB,XR,AM(1),AM(3),WT
          C     ****************************************************************
          C     READ LOADED SURFACE AREA CARD-CARD TYPE 9-FOR GENERAL STRUCTURE
          C     OPTION
          C     ****************************************************************
000211          READ(2,430)AFACE
          C     ****************************************************************
          C     READ LOADED SURFACE CENTROID CARDS-CARD TYPE 10-ONE CARD/SURFACE
          C     FOR GENERAL STRUCTURE OPTION
          C     ****************************************************************
000217          READ(2,43)(XCORD(K),YCORD(K),K=1,NLOAD)
          C     ****************************************************************
          C     READ LOADED SURFACE NORMAL VECTOR CARDS-CARD TYPE 11-ONE CARD PER
          C     SURFACE-FOR GENERAL STRUCTURE OPTION
          C     ****************************************************************
000234          READ(2,43)((UVECT(K,J),J=1,2),K=1,NLOAD)
000253          GO TO 44
000254       41 CONTINUE
          C     ****************************************************************
          C     COMPUTE WEIGHT, MASS AND MASS MOMENT OF INERTIA OF STRUCTURE FOR
          C     NORMAL AND SPECIAL LOADING OPTIONS
          C     ****************************************************************
000254          VOL=0.0
000255          IF(N-4) 32,31,32
000257       31 VOLSW=2.*BS*HW*TW/12.**3
000264          VOLB=BS*(CL+2.*TW)*TW/12.**3
000273          VCLBW=(CL +2.*TW)*HW*TW/12.**3
000301          VOLFS=(CL + 2.*TW)*BB*TS/12.**3
000306          GO TO 33
000307       32 VOLSW = (N-1)* BS * HW * TW /12.**3
000316          VOLBW=(CL +(N-1)*TW)*HW*TW/12.**3
000327          VOLFS=(CL + (N-1)*TW)*BB*TS/12.**3
000337       33 VOL=VOLSW+VCLBW+VCLFS+VCLB
000343          WT = 490. * VCL
000345          AM(1) = WT /386.
000347          AM(2) = AM(1)
          C     ****************************************************************
          C     COMPUTE LOCATIONS OF CENTER OF GRAVITY OF STRUCTURE AND CENTROIDS
          C     OF LOADED SURFACES-FOR NORMAL AND SPECIAL LOADING OPTIONS
          C     ****************************************************************
000350          XB=((VOLSW+VCLB)*(BS+TW)/2.+VCLFS*(BS+TW/2.-BB/2.))/VOL-TW/2.
000364          YB=((VCLSW+VCLBW)*HW/2.-VOLFS*TS/2.+VOLB*(HW+TS/2.))/VOL
000376          XP = XB -ES
000400          XCORD(1) = XP
000401          XCORD(2)=XP-ES+BB/2.
000404          YCORD(1) =-HW/2.+YB
000407          YCORD(2) = YB
000410          AISW  = VCLSW*((BS*BS+HW*HW)/12.+(BS/2.-XB)**2+(HW/2.-YB)**2)
000424          AIBW  = VCLBW*((TW*TW+HW*HW)/12.+(XCORD(1)+TW/2.)**2+YCORD(1)**2)
000430          AIFS  = VOLFS*((TS*TS+BB*BB)/12.+XCORD(2)**2+ (YCORD(2)+TS/2.)**2)
```

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000450          AIB=VCLB*((TM*TM+BS*BS)/12.+(TS/2.-YB)**2+(HW+TS/2.-YB)**2)
000466          AM(1)=(AISW+AIBW+AIFS+AIB)*153./386.
        C       ****************************************************************
        C       PRINT INERTIAL PROPERTIES OF STRUCTURE
        C       ****************************************************************
000473          WRITE(5,500)X9,Y9,X0,AM(1),AM(3),WT
000512          XCORD(2)=XB-.5*TS
000515          XCORD(3)=XCORD(2)
000516          YCORD(1)=.5*HW  + YB
000521       43 FORMAT(2F10.0)
000521      410 FORMAT(4F10.0)
        C       ****************************************************************
        C       COMPUTE TIME HISTORY OF BLAST LOADS ON STRUCTURE
        C       ****************************************************************
000521       44 IF(NLOAD) 19,39,14
000523       14 IP=NLOAD
000524          GO TO 28
000525       19 IF(N-4) 15,36,36
000530       15 IP=2
000531          GO TO 28
000532       36 IP=3
000533       28 DO 29 NOB=1,NP
000535          WRITE(5,1700)KDESC
000542          WRITE(5,600)
000546          WRITE(5,179)NOB
000554          IF(NLOAD)26,26,27
        C       ****************************************************************
        C       PRINT CHARGE WEIGHT, CHARGE LOCATION PARAMETERS AND IMPULSES ON
        C       BACKWALL, FLOOR AND ROOF-FOR NORMAL OPTION ONLY
        C       ****************************************************************
000556       26 WRITE(5,1003)(DATA(NOB,I),I=1,4)
000572          IF(IP-1)46,40,40
000575       40 WRITE(5,1001)DATA(NOB,5)
000603       46 WRITE(5,1002)(DATA(NOB,I),I=6,7)
        C       ****************************************************************
        C       COMPUTE TIME HISTORY OF BLAST LOADS ON EACH SURFACE PRODUCED BY
        C       EACH EXPLOSIVE CHARGE
        C       ****************************************************************
000617       27 DO 28 K=1,IP
000621          P2P1=0.0
000622          IF(NLOAD)25,25,26
        C       ****************************************************************
        C       READ SURFACE LOADING DATA CARDS-CARD TYPE TYPE 12-ONE CARD/SURFACE
        C       FOR SPECIAL LOADING AND GENERAL STRUCTURE OPTIONS
        C       ****************************************************************
000624       26 READ(2,410)DATA(NOB,K+2),TT(NOB,K,1),TT(NOB,K,2),P2P1
000644       25 P=2.0*DATA(NOB,K+2)/(1000.0*(TT(NOB,K,2)-TT(NOB,K,1)))
000660          P2=P/(1.+P2P1)
000663          P1=P2P1*P
000665          AN=(P-P1)/(TT(NOB,K,1)-TT(NOB,K   ))
        C       ****************************************************************
        C       PRINT AREA OF SURFACE AND LOCATION OF CENTROID OF SURFACE
        C       RELATIVE TO CENTER OF GRAVITY OF STRUCTURE
        C       ****************************************************************
000677          WRITE(5,700)AFACE(K),XCORD(K),YCORD(K)
```

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              C     *****************************************************************
              C     PRINT TIME HISTORY OF BLAST PRESSURES ON SURFACE
              C     *****************************************************************
000713              WRITE(5,4001)F,TT(NOB,K,1),P1,TT(NOB,K,2)
000721              WRITE(5,105)
000725              DO 10 J=1,NUMTM
000727              TJ=TASM +(J-1)*DELTM
000734              IF(TJ-TT(NOB,K,1)) 10,15,15
000741           15 IF(TJ-TT(NOB,K,2)) 17,17,20
000746           17 IF(J-1000)14,14,1400
000751           14 PNREQ = P          6**(TJ-TT(NOB,K,1))
000760              ASLAJ = AFACE(K) *PNREQ
000762              FVREQ   = ASLAJ * UVECT(K,2)
000763              FHREQ   = ASLAJ * UVECT(K,1)
000765              FTHET   = FVREQ   *XCORD(K) -FHREQ   * YCORD(K)
000770              F(1,J)=F(1,J)+FHREQ
000773              F(2,J)=F(2,J)+FVREQ
000776              F(3,J)=F(3,J)+FTHET
              C     *****************************************************************
              C     PRINT TIME HISTORIES OF BLAST LOADS ON EACH SURFACE PRODUCED
              C     BY EACH CHARGE
              C     *****************************************************************
001001              WRITE(5,9) J,TJ     ,FHREQ   ,FVREQ   ,FTHET
001017           10 CONTINUE
001022           20 CONTINUE
001025           29 CONTINUE
001027              DO 100 J=1,1000
001031              K=1001-J
001033              IF(F(1,K) + F(2,K) + F(3,K))450,100,450
001041          100 CONTINUE
001043          450 KTIME = K
001045              IF(IC2)50,50,22
001046           22 WRITE(5,1700)KDESC
001054              WRITE(5,600)
001060              WRITE(5,106)
001064              DO 460 J=1,KTIME
              C     *****************************************************************
              C     PRINT TIME HISTORIES OF RESULTANTS OF BLAST LOADS ON STRUCTURE
              C     *****************************************************************
001066              TJ=TASM +(J-1)*DELTM
001073          460 WRITE(5,9)J,TJ,(F(I,J),I=1,3)
001115              WRITE(5,1500)TJ
001122         1500 FORMAT(/5X,36HFORCE VECTOR EQUALS ZERO AFTER TIME ,F7.5/)
001122           50 LATONY1
001123           57 IBP= VB +     TW +     MALNM
001126              CALL GRMT2
001127            9 FORMAT(     I5,F10.5,3E16.6 )
001127          105 FORMAT(12H          TIME   ,5X,9H FORCE X ,7X,29H FORCE Y      MOME
                   1NT ABOUT Z ,/,17H          (SEC) ,5X,9H  (LBS)  ,7X,24H  (LBS)
                   2       (IN-LBS)     /)
001127          106 FORMAT(    17H          TIME   ,5X,9H FORCE X ,7X,24H FORCE Y
                   1MOMENT ABOUT Z ,/,17H          (SEC) ,5X,9H  (LBS)  ,7X,24H  (LBS
                   2)          (IN-LBS)     /)
001127          600 FORMAT(25X,52HHORIZONTAL DISTANCE FROM CG TO NEAR FACE OF WALL(IN)
                   1,4X,F10.3,/,25X,50HVERTICAL DISTANCE FROM TOP OF FLOOR SLAB TO CG(
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              2IN),10X,F10.3,/,25X,40HDISTANCE FROM CG TO REAR END OF SLAB(IN),20
              3X,F10.3,/,25X,18HMASS(LB-SEC**2/IN),42X,F10.1,/,25X,36HMASS MOMENT
              4 OF INERTIA(LB-IN-SEC**2),14X,E20.5,/,25X,11HWEIGHT(LBS),35X,E20.5
              5)
001127     600 FORMAT(    29X,7HLOADING,/,29X,7H-------/)
001127     700 FORMAT(/5X,19HAREA OF FACE(IN**2),36X,F10.1,/,5X,51HHORIZONTAL DIS
              1TANCE FROM CENTROID OF AREA TO CG(IN),4X,F10.1,/,5X,49HVERTICAL DI
              2STANCE FROM CENTROID OF AREA TO CG(IN),6X,F10.1/)
001127     800 FORMAT(5X,19HPRESSURE TIME CURVE,/,5X,19H-------------------,//,5X
              1,22HPOINT 1 PRESSURE(PSI) ,F7.1,5X,10HTIME(SEC) ,F7.5,/,5X,22HPOIN
              2T 2 PRESSURE(PSI) ,F7.1,5X,10HTIME(SEC) ,F7.5/)
001127    1100 FORMAT(1H1,25X,35A2//)
001127    1200 FORMAT(25X,18HSTRUCTURE GEOMETRY,/,25X,18H------------------,/,25X
              1,22HBACKWALL THICKNESS(IN),38X,F10.3,/,25X,45HRATIO OF SLAB THICKN
              2ESS TO BACKWALL THICKNESS,15X,F10.3,/,25X,22HLENGTH OF BACKWALL(FT
              3),38X,F10.3,/,25X,22HHEIGHT OF BACKWALL(FT),38X,F10.3,/,25X,46HRAT
              4IO OF WIDTH OF FLOOR TO TOTAL WIDTH OF BASE,14X,F10.3,/,25X,44HRAT
              5IO OF HEIGHT OF WALL TO BASE OF STRUCTURE,16X,F10.3)
001127    1300 FORMAT(25X,17HWIDTH OF BASE(IN),43X,F10.5,/,25X,32HWIDTH OF LOADED
              1 AREA ON BASE(IN),28X,F10.3,/,25X,18HSLAB THICKNESS(IN),42X,F10.3,
              2/,25X,45HRATIO OF WALL THICKNESS TO WIDTH OF STRUCTURE,15X,F10.3)
001127    1700 FORMAT(1H1,1X,35A2//)
001127    1799 FORMAT(5X,14HCHARGE NUMBER ,I3,/,5X,17H-----------------/)
001127    1800 FORMAT(5X,36HMIN DISTANCE FROM CHARGE TO WALL(FT),19X,F10.3,/,
              15X,18HCHARGE WEIGHT(LBS),37X,F10.1,/,5X,23HIMPULSE ON WALL(PSI-MS)
              2,32X,F10.1,/,5X,24HIMPULSE ON FLOOR(PSI-MS),31X,F10.1)
001127    1801 FORMAT(5X,23HIMPULSE ON ROOF(PSI-MS),32X,F10.1)
001127    1802 FORMAT  (5X,44HMIN DISTANCE FROM CHARGE TO EDGE OF WALL(FT),11X,
              3 F10.3,/,5X,37HHEIGHT OF CHARGE ABOVE FLOOR SLAB(FT),18X,F10.3/)
001127    2000 FORMAT(//1X,112HNUMBER OF FORCE TIME STATIONS EXCEEDS CAPACITY OF
              1PROGRAM JOB ABORTED  INCREASE SIZE OF ARRAY F(3,    ) IN COMMON///)
001127         RETURN
           C   ****************************************************************
           C   PRINT MESSAGE INDICATING INSUFFICIENT STORAGE FOR LOAD TIME
           C   HISTORIES
           C   ****************************************************************
001130    1400 WRITE(5,2000)
001134         RETURN
001135         END
```

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               SUBROUTINE CRNT2
000002         DIMENSION RESP(3,1000),RESIST(3,1000),VELOC(3,1000),ACCEL(3,1000)
000002         DIMENSION STRESS(15,1000),TIME(1000)
000002         DIMENSION        R(3)     ,VX(3)     , RMAXP(15),RMAXN(15),
              1 SM(15),XK(15),YK(15),TLAST(15),ISIG(15),UM7EL(15),
              2 IY(15),U(15),XSET1(15),XSAVE(3),R1(15),
              3 LSIG(15),XSET(15),XLAST(15)
              4,HLAST(15),HCONT(15),TS(15),AXIJ(3),XIJ(3),XIJM1(3),XIJP1(3),
              5 AXIJP(3),DMAX(3),DMIN(3),FF(3)
000002         COMMON C9, NF, TWOT, IOTC,IC1,IC2,CRSW, ICTME,KDESC(35),NWALL,
              $       IOT,L,NS,E1,E2,SPTP,XMEU,YMEU,BTAX,BTAY,HW,BB,CL,BS,TS,TW,
              $F(3,1000),TJ,TASM,DELT,NJ,DUMMY(15),TZ,HS,TWP,NUMPT,KTIME,W,AM(3),
              $H,XR,XBP,TLANK(2),NOEL2,ANUMP,BLINK(200),DATA(20,7),DC,PV,PW,X,Y,
              $FDS,XKLMU,RU,RUP,X1,TWALL,XIB,B,NK,VK,AVEL,VF,NFON
000002         IWALL=0
000003         ITYPE =1
000004         N = 3
000005         AL = 88
000007         XKLMP=.66
000010         X15L=(BB + XR - XBP)*.15  + XBP
000014         DO 285  JJ=1,KTIME
          C    ****************************************************************
          C    INITIALIZE RESPONSE VARIABLES TO ZERO
          C    ****************************************************************
000016     285 F(2,JJ) = F(2,JJ) + W
000023         DO 113 I=1,3
000025         R (I)  = 0.
000026         AXIJ(I)=0.0
000027         XIJ(I)=0.0
000030         XIJM1(I)=0.0
000031         XIJP1(I)=0.0
000032         AXIJP(I)=0.0
000033     113 VX(I)  = 0.
000036         H = H + TS
000040         ALXR = AL + XR
000042         RMY =H*H +  ALXR*ALXR
000044         AR= SQRT(RMY)
000046         ANCGT  = ATAN ( H /ALXR)
000052         U(1) = XR
000053         NS1 = NS -1
000055         ASPC = R*AL/NS
000060         IF(XMEU-1.0)10,10,9
000063       9 XMEU=.0069444*XMEU
000065         FRICT=XMEU*ASPC
000067         ITYPE=2
000070      10 DO 116 I=2,NS
000072     116 U(I) = U(1) + (I-1)*AL /NS1
000103         SM1 = 2.*W*(2. + 3.*XR/AL)/R/AL
000112         SM2 =-2.*W*(1. + 3.*XR/AL)/R/AL
000121         ALP=SM1*(1.+XR/AL)-SM2*XR/AL
000127         BET=(SM2-SM1)/AL
000131         GO TO(11,12),ITYPE
000137      11 TAVEL       = - XMEU* SM1
000141         TAUFR       = - XMEU* SM2
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```
000143          GO TO 13
000144       12 TAUEL=-XMFU
000146          TAUER=TAUEL
000147       13 DO 19 I=1,N
000151          P(I)=0.0
000152          AAX      = F(I,1) /AM(I)
000154          BAX      = F(I,2) /AM(I)
000156          AXIJ(I)= .5*AAX  +(BAX-AAX)/6.0
000163          VX (I)   =AXIJ(I)*DELT
000165       19 XIJ(I)=AXIJ(I)*DELT*DELT
000171          IS = 0
000172          IR = 0
000173          T2=0.0
000174          T3= 0.
000175          UMAXP= 0.
000176          JNUM=0
000177          KNUM=1
000200          JP=0
000201          AMAXT=0.0
000202          DO 91 I=1,3
000203          DMAX(I)= 0.
000204       91 DMIN(I)= 0.
000207          VMAX=0.0
000210          XMAX=0.0
000211          DO 100 I=1, NS
000212          XSET1(I)=0.0
000213          LSIG(I)=0
000214          XSET(I)=0.0
000215          SM(I)=ALP + BET*U(I)
000221          XLAST(I)=(SMTP-SM(I ))*ASPG/(E1*VK)
000226          WLAST(I)=0.0
000227          WCONT(I)=0.0
000230          TS(I)=0.0
000231          WMAXP(I)=0.0
000232          WMAXN(I)=0.0
000233          TLAST(I)=0.0
000234          ISIG(I)=0
000235          UMZEL(I)=0.9
000236          STRESS(I,1)=SM(I)
000240      100 IV(I)=0
000243          YIMAX=SM(10)   *ASPG/(E1*VK)
000246          YORIG=YIMAX
000247          TTMAX=TASH
000250          IF(LTIME-2)101,101,102
000253      101 LTIME=21
000254          GO TO 103
000255      102 LTIME=LTIME
000257      103 LSAVE=LTIME-NCELP
000261          LSW=LTIM
000262          PIPI=W
000263          TIPT(1)=TASP
000265          DO 99 K=1,3
000266          RESP(K,1)=XIJ(IV)
000270          RESTAT(K,1)=P(K)
000271          VELOC(K,1)=0.0
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000272      95 ACCEL(K,1)=AXTJ(K)
000275         J = 2
000276         IF(SM1-SM2)9000,9000,9001
000301    9000 PRMAX=SM2
000303         GO TO 118
000303    9001 PRMAX=SM1
000305     118 P(2)=0.0
000306         IF(J-LSW)1189,1190,119
000311    1189 TJ=TASH+(J-1)*DELT
000317         GO TO 1188
000317    1190 TSW=TJ+DELT
000321         TJ=TSW
000322         DELT=NDELZ*DELT
000324         GO TO 1189
000326     119 TJ=TSW +(J-LSW)*DELT
000332    1188 R(1)   =2.
      C        ****************************************************************
      C        CALL SUBROUTINE DEDE TO COMPUTE FORCES IN VERTICAL SOIL ELEMENTS
      C        ****************************************************************
000333         CALL DEDE(IY,XR,AL,SM1,SM2,E1,E2,TIJ,ASFG,XK,YK,NS,HK,VK,C,VE,J,
              1 SMTP,R,LSIG,SP,ALP,UET,XSET,XLAST,XSET1,HLAST,HCONT,H,TS,TJ,
              2TIJ-1,TLAST,ISIG,UMZEL)
000376         R(1)   =0.
      C        ****************************************************************
      C        CALL SUBROUTINE UPCHK TO DETERMINE WHETHER OR NOT STRUCTURE WAS
      C        SEPARATED FROM SOIL
      C        ****************************************************************
000377         CALL UPCHK(NS,SP,ASPG,XMEU,XPSL,UMAXP,DMAXH,RL,ITYPE,FRICT)
000411         IF(XPSL)150,150,151
000413     150 TT=0.0
000414         IQ=0
000415         IS=0
000416         UMAXP=0.0
000417         GO TO 200
000417     151 IF(IT) 99,156,177
000421     156 IF(IR) 99,256,367
000423     256  IF(IS) 99, 257, 265
000425     257 TALEL=0.0
000426         XPSL=0.0
      C        ****************************************************************
      C        MONITOR HORIZONTAL DISPLACEMENT OF FOUNDATION TO DETERMINE
      C        HORIZONTAL RESISTANCE FORCES IN SOIL
      C        ****************************************************************
000427         UU=(TJ(1)-U**(N+1)(J)(3))
000433         DO 258 K=1,NS
000435         IF(SP(K))258,258,2259
000437    2259 GO TO(2260,2261),ITYPE
000445    2260 PHAXP(K)=XMEU*SP(K)*ASPG
000451         GO TO 2240
000451    2261 PMAXP(K)=FRICT
000453    2240 IF(UU-HCONT(K))2250,2251,2257
000456    2250 PMAXP(K)=-PMAXP(K)
000460    2257 XPSL=XPSL +PMAXP(K)
000463         IF(HLAST(K))2263,2262,2263
000466    2262 P(K)   =    (UU-HCONT(K))*P(K)
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000470        TAUEL=TAUEL + R1(K)
000472        GO TO 250
000472   2263 IF(ISIG(K))2264,2264,2270
000474   2264 R1(K) =        (UU-HLAST(K))*E2*HK + (HLAST(K)-HCONT(K))*E1*HK
000505        IF(ABS(R1(K))-ABS(TLAST(K)))2266,2266,2265
000513   2265 TLAST(K)=R1(K)
000514        UNZEL(K)=UU-HCONT(K)
000520        TAUEL =TAUEL + R1(K)
000522        GO TO 250
000522   2266 ISIG(K)=1
000524   2270 IF(E1-E2)2267,2267,2268
000527   2267 XK(K)=E2*HK
000532        GO TO 2269
000532   2268 XK(K)=E1*HK
000535   2269 R1(K)=TLAST(K)-XK(K)*(UNZEL(K)-UU +HCONT(K))
000543        TAUEL =TAUEL + R1(K)
000545    250 CONTINUE
000550        TAUE=ABS(TAUEL) - ABS(RMSL)
000555        IF(TAUE)262,262,261
000556    262 R(1)=TAUEL
000563        DO 2690 I=1,NS
000561   2690 R(3)=R(3)-R1(I)*(H*COS(XIJ(3)) +U(I)*SIN(XIJ(3)))
000574        GO TO 200
000575    261 IS=IS+1
000577        IF(J-2)272,272,269
000601    272 R(1)=RMSL
      C       ****************************************************************
      C       CALL SUBROUTINE R3 TO FIND MOMENT OF HORIZONTAL SOIL RESISTANCE
      C       FORCES ABOUT CENTER OF GRAVITY OF STRUCTURE
      C       ****************************************************************
000603        CALL R3(NS,SM,R,H,U,XIJ,RMSL)
000611        GO TO 200
000612    269 UU=XIJ(1) -H*SIN(XIJ(3))
000617        UUU=XIJM1(1)-H*SIN(XIJM1(3))
000624   2650 RMSL=0.0
000625        DO 266 I=1,NS
000627        GO TO(45,401,ITYPE
000635     40 IF(SP(I))41,41,43
000637     41 RHASP(I)=0.0
000641        GO TO 266
000641     43 RHASP(I)=FRIC
000643        GO TO 44
000644     45 RHASP(I)=SMEL*SP(I)*ASPE
000650     44 IF(UU-HCONT(I))267,268,268
000652    267 RHASP(I)=-RHASP(I)
000655    268 RMSL=RMSL + RHASP(I)
000663    266 CONTINUE
000662        VV=(ABS(UU) -ABS(UUU))/DELT
000670        IF(VMSL)2710,2710,2711
000671   2710 IF(UU)2713,2712,2712
000673   2711 IF(UU)2712,2714,2714
000675   2712 VV=-VV
000676        GO TO 2717
000677   2713 IF(UUU)2717,2717,2719
000701   2714 IF(UUU)2719,2719,2717
```

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000702    2715 IF(JV)2712,2712,2717
000705    2717 IF(VV)271,271,272
000707     271 I2=IJ
000711         IR=I2+1
000712         UMAXP=X(J(I)-HMSTN(I2J(3)))
000717         GO TO 272
000723     362 UM=X(J(I)-HMSTN(I1J(3)))
000724         R(I)=0.0
000726         DO 81 I=1,N7
000730         IF(SM(I))81,81,82
000732      80 IF(HCONT(I))81,82,81
000734      83 IF(IS(I)-I2)82,85,86
000737      88 IF(HLAST(I))86,85,86
000741      86 IF(ISIG(I))862,860,860
000743     860 R(I)=   E1*HM*(HCONT(I)-HLAST(I)) + E2*HM*(HLAST(I)-UU)
000754         RMAXP(I)=0.0
000756         IF(ABS(R(I))-ABS(LAST(I)))870,870,865
000763     865 LAST(I)=R(I)
000765         UMZEL(I)=HCONT(I)-UU
000770         GO TO 818
000772     870 ISIG(I)=1
000772     860 IF(I2-I2)875,875,883
000775     875 [illegible]
001000         GO TO 893
001020     880 [illegible]
001003     890 R(I)=LAST(I)-[illegible]*(UMZEL(I) + UU -HCONT(I))
001011         RMAXP(I)=0.0
001012         GO TO 818
001013      85 R(I)  +   [illegible]*(HCONT(I)-UU)
001017         UMAXP(I)=0.0
001020         GO TO 818
001020      82 IF(HLAST(I))819,930,819
001022     819 IF(I2-I2)820,820,925
001024     820 IF(UMAXP-UU)821,822,822
001035     821 IF(UMAXP-HLAST(I))823,824,824
001036     822 IF(HLAST(I)-UMAXP)823,824,824
001037     823 R(I)=E2*HM*(UMAXP-HLAST(I)) +E1*HM*(HLAST(I)-UU)
001050         GO TO 818
001051     824 [illegible]
001054         GO TO 833
001054     825 [illegible]
001057     830 R(I)=      [illegible]*(UMAXP-UU)
001063     818 [illegible]
001067      81 CONTINUE
001072         IF([illegible])12633,12636
001073   12633 [illegible]
001101   12636 [illegible]
001123         DO 12625 I=1,N7
001104         IF([illegible])12625,12625,12673
001106   12673 [illegible]
001110   12625 CONTINUE
001112         GO TO 12665
001117   12660 [illegible]
001119   12665 IF([illegible])12631,12631,12631
001120   12631 [illegible]=0.0
```

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```
001121          IR=0
001122          IS=1
001123          DO 12632 I=1,NS
001124          TLAST(I)=0.0
001125          ISIG(I)=0
001126          R(I)=0.5
001127    12632 UMZEL(I)=0.0
001132          GO TO 2698
001133     1263 DO 1264 I=1,NS
001135     1264 R(I)=R(I)- (WMAS*(I-R(I))*(W*COS(XIJ(I))) +U(I)*SIN(XIJ(I))))
001153          GO TO 200
001153      172 SMSL=0.0
001154          DO 173 I=1,NS
001156          GO TO(1740,1742),ITYPE
001164     1740 IF(YMC(I))1741,1741,1742
001166     1741 BMASN(I)=0.5
001170          GO TO 1739
001172     1742 BMASN(I)=FR(C)
001172          GO TO 1739
001173     1738 BMASN(I)=SMSL*ASPC*SN(I)
001177     1739 SMSL=SMSL + BMASN(I)
001202      173 CONTINUE
001204          IF(ABS(R(1))-ABS(SMSL))175,2720,2720
001211      175 IF(IJ)1790,1790,1263
001213     1790 IJ=IJ
001215      177 GO TO 307
001216     2720 IJ=0.0
001217          IR=0
001220          IS=1
001221          DO 2721 I=1,NS
001222          TLAST(I)=0.0
001223          ISIG(I)=0
001224          UMZEL(I)=0.0
001225          R(I)=0.0
001226     2721 BMAS(I)=BMASN(I)
001232          R(1)=-SMSL
       C        ******************************************************************
       C        CALL SUBROUTINE RS TO FIND MOMENT OF HORIZONTAL SOIL RESISTANCE
       C        FORCES ABOUT CENTER OF GRAVITY OF STRUCTURE
       C        ******************************************************************
001233          CALL RS(NS,SP,D,H,Q,XIJ,SMSL)
001242          GO TO 200
001242      200 DO 201 I=1, N
001245          R(I)=X(I)
001247          IF(I-5)2010,2010,2020
001251     2010 RI=R(I,J)
001254          GO TO 2030
001255     2015 GO TO(2025,2026,2027),I
001256     2020 RI=0
001260          GO TO 2030
001264     2029 RI=1.6
       C        ******************************************************************
       C        COMPUTE ACCELERATIONS OF STRUCTURE USING EQUATIONS (2.11,12.21 -
       C        12.31)
       C        ******************************************************************
```

```
001267   2830 AXIJ(I)=(FIJ-R(I))/AM(I)
001273        FF(I)=FIJ
001274        IF(J-LSH) 2812,2813,2812
            C     ****************************************************************
            C     COMPUTE DSIPLACEMENTS OF STRUCTURE USING RECURSION FORMULA
            C     ****************************************************************
001276   2813 XIJP1(I)=XIJ(I)*2.0  -XSAVE(I) + AXIJ(I)*DELT*DELT
001304        GO TO 2814
001304   2812 XIJP1(I)=XIJ(I)*2.0 -XIJM1(I) +AXIJ(I)*DELT*DELT
            C     ****************************************************************
            C     COMPUTE AVERAGE VELOCITY OVER TIME INCREMENT
            C     ****************************************************************
001312   2814 VX(I)=(XIJP1(I)-XIJ(I))/DELT
001316        IF(J-LSAVE) 281,2811,281
001320   2811 XSAVE(I)=XIJ(I)
001322    281 CONTINUE
001325        IF(J-LTIME)  3022,3019,3022
001327   3019 ANUMP=NUMPT
001331        NUMPT=NUMPT/NDEL2
001334   3022 JNUM=JNUM + 1
001336        IF(JNUM-NUMPT)3030,3020,3020
001340   3020 JNUM=0
001341        KNUM=KNUM +1
001343        IF(KNUM-1000)3021,3021,283
001345   3021 TIME(KNUM)=TJ
001347        DO 94 K=1,3
001351        RESP(K,KNUM)=XIJ(K)
001354        RESIST(K,KNUM)=R(K)
001357        ACCEL(K,KNUM)=AXIJ(K)
001362     94 VELOC(K,KNUM)=R1(K)
001367        DO 92 K=1,NS
001370     92 STRESS(K,KNUM)=SM(K)
001376   3030 IF(XIJP1(2)) 303, 303, 300
001400    303 GAMA = ANCGT + XIJP1(3)
001402    300 IF(XIJP1(3)) 301, 301, 302
001404    302 IF(XIJP1(3) -XIJ(3)) 305, 501, 501
001407    501 ALPHA = ANCGT + XIJP1(3)
001411        IL=0
001412        IF (ALPHA - 1.571) 502, 503, 503
001415    502 IF(XIJP1(3)-AMAXT)305,305,334
            C     ****************************************************************
            C     PRINT MESSAGE INDICATING STRUCTURE OVERTURNS
            C     ****************************************************************
001420    503 WRITE (5,504) TJ
001426        AMAXT=XIJP1(3)
001430        IL=1
001431    504 FORMAT(////,29H STRUCTURE OVERTURNS AT TIME ,F10.5)
001431        GO TO 283
001431    305 IL = -1
001432        IF(XIJP1(3)-AMAXT)301,301,334
001435    334 AMAXT = XIJP1(3)
001437    301 IF(NWALL) 350,350,351
001441    351 IF(TWALL) 354,354,350
001443    354 IF(TJ-TWALL)350,352,352
001446    352 IF(VF)353,353,355
```

```
001450      355 WRITE(5,1500)TJ
001456          IL=-1
001457          GO TO 286
001460      353 WRITE(5,1505)TJ
001466          IWALL=1
001467      350 JP = J+1
001471          IF (JP - NJ) 202, 203, 203
001473      202 DO 21 I=1,3
001475          IF(XIJP1(I) -DMAX(I) ) 22,22,23
001500       23 DMAX(I) = XIJP1(I)
001502       22 IF(XIJP1(I) -DMIN(I)) 29,29,21
001505       29 DMIN(I) = XIJP1(I)
001507       21 CONTINUE
001511          IF(NFON)26,26,27
         C      ***************************************************************
         C      CALL SUBROUTINE FON TO COMPUTE SHEARS AND BENDING MOMENTS FOR
         C      FOUNDATION EXTENSION OF CANTILEVER WALL BARRIER
         C      ***************************************************************
001513       27 CALL FON(NS,U,XBP,X15L,SM,VMAX,XMMAX,XMAX,TS)
001524       26 IF(SM(NS) - FRMAX)32,32,33
001527       33 PRMAX = SM(NS)
001531       32 J=J+1
001533          DO 117 I=1,3
001534          XIJM1(I)=XIJ(I)
001536          XIJ(I)=XIJP1(I)
001537      117 AXIJP(I)=AXIJ(I)
001542          YTOE=XIJ(2) +U(NS)*SIN(XIJ(3)) + YORIG
001551          IF(YTOE-YTMAX)1101,1101,110
001553     1101 YTMAX=YTOE
001555          TTMAX=TJ
001556          GO TO 110
001557      203 DELT = DELT /NDEL2
001561          NUMPT=ANUMP
         C      ***************************************************************
         C      PRINT STRUCTURAL AND RESPONSE PARAMETERS FOR BACK WALL ELEMENT
         C      ***************************************************************
001563          IF(NWALL)286,286,286
001565      286 WRITE(5,19)KDESC
001573          GO TO(287,288,288,288),L
001603      287 WRITE(5,1501)DC,PV,FOS,RU,XIB,TWALL
001623          GO TO 2841
001624      288 IF(X)289,289,290
001626      289 WRITE(5,1502)DC,PV,PH,Y,FOS,XKLMU,XKLMP,RU,RUP
001654          GO TO 2840
001655      290 WRITE(5,1503)DC,PV,PH,X,FOS,XKLMU,XKLMP,RU,RUP
001703     2840 WRITE(5,1504)X1,XIB,TWALL
001715     2841 IF(VF)284,284,2839
001717     2839 WRITE(5,1506)VF
001724      284 IF(ICP)697,697,696
         C      ***************************************************************
         C      PRINT DISPLACEMENTS OF STRUCTURE AND SOIL RESISTANCE FORCES
         C      ***************************************************************
001727      696 WRITE(5,19)KDESC
001735          WRITE (5,202)
001741          WRITE (5,906 )
```

```
001745          WRITE(5,1507)
001751          NLINE=0
001752          DO 20' J = 1, KNUM
001754          NLINE=NLINE + 1
001756          IF(NLINE-48)2004,2004,2003
001760     2003 NLINE=1
001761          WRITE(5,15)KDESC
001767          WRITE(5,202)
001773          WRITE(5,204)
001777          WRITE(5,1507)
002003     2004 XFON=RESP(1,J)-H*SIN(RESP(3,J))
002013          RESP(3,J)=57.296*RESP(3,J)
002016      203 WRITE(5,104)TIME(J),(RESP(K,J),K=1,3),(RESIST(K,J),K=1,3),XFON
002050          IF(NVEL)1202,1202,1201
           C    **************************************************************
           C    PRINT ACCELFRATOONS AND VELOCITIES OF STURCUTRE
           C    **************************************************************
002051     1201 WRITE(5,15)KDESC
002057          WRITE(5,201)
002063          WRITE(5,204)
002067          WRITE(5,1500)
002073          NLINE=0
002074          DO 208 J=1,KNUM
002076          NLINE=NLINE + 1
002100          IF(NLINE-48)2007,2007,2055
002102     2055 NLINE=1
002103          WRITE(5,15)KDESC
002111          WRITE(5,201)
002115          WRITE(5,204)
002121          WRITE(5,1500)
002125     2007 VFON=VELOC(1,J)-H*VELOC(3,J)*(COS(RESP(3,J)/57.296))
002141      208 WRITE(5,104)TIME(J),(ACCEL(K,J),K=1,3),(VELOC(K,J),K=1,3),VFON
002174      201 FORMAT(              19X,22H ACCELERATION OF C.G. ,33X,
               118H VELOCITY OF C.G. /)
002174     1202 IF(ICT) 697,1203, 697
           C    **************************************************************
           C    PRINT SOIL BEARING PRESSURES AT SOIL ELEMENT ATTACHMENT POINTS
           C    **************************************************************
002175     1203 WRITE(5,15)KDESC
002203          DO 2206 J=1,NS
002205     2206 IY(J)=J
002210          WRITE (5,205)(IY(J),J=1,NS)
002223          WRITE(5,2205)
002227          NLINE=0
002230          DO 206  J=1, KNUM
002232          NLINE=NLINE +1
002234          IF(NLINE-48)2006,2006,2005
002236     2005 NLINE=1
002237          WRITE(5,15)KDESC
002245          WRITE(5,205)(IY(K),K=1,NS)
002260          WRITE(5,2205)
002264     2006 WRITE(5,207)TIME(J),(STRESS(K,J),K=1,NS)
002302      206 CONTINUE
002305      697 IF(VYMAX)1100,1103,1103
002307     1100 VYMAX=-VYMAX
```

```
002310        WRITE(5,1182)YTMAX,TTMAX
002320   1182 FORMAT(//1X,50HMAX VERTICAL DISPLACEMENT OF TOE ABOVE THE GROUND ,
             1F6.2,10H  AT TIME ,F10.5/)
002320        GO TO 1185
002321   1183 WRITE(5,1186)YTMAX,TTMAX
002331   1186 FORMAT(//1X,54HMINIMUM VERTICAL DISPLACEMENT OF TOE BELOW THE GROU
             1ND ,F6.2,10H  AT TIME ,F10.5/)
002331   1185 IF( IOTC) 698,698,699
002333    699 CALL MULTB
002334    698 IF(IL) 14, 16, 307
002336    307 IF(IC1)308,308,99
002340     14 IF(IC1)701,701,6900
002342    701 IF( IOT) 704,704,702
002344    702 DTW =-TNOT +TW
002346        DTWTW = DTW / TNOT
002347        IF(DTW-2.0)607,607,707
002352    707 IF ( DTWTW-0.025)607, 607,  708
002355    708 DTW2 = DTW /2.
002357        TW = TNOT + DTW2
002361        TS = C9 *TW
002363        CALL CGTH2
002364    704 IOT = -1
002365        TNOT = TW
002367        TW = TW/2.
002370        TS = TW*C9
002372        IF ( TW-12.    ) 705, 706, 706
002374    705 WRITE ( 5,710)
002400    710 FORMAT(//33H WALL TOO THIN, GO TO NEXT POINT  )
002400        CALL MULTB
002401    706 CALL CGTH2
002402    607 IOTC= 1
002403        WRITE ( 5,609) NP, CL, HW, TW  , CRSW, L
002423    609 FORMAT(///11H PT NO. = ,I2,/6H CL = ,F10.2,/ 8H H     = ,F10.2,/
             119H  WALL THICKNESS = ,F10.3,/6H CRCW=,F10.2,/11H PANEL TYPE,
             1I10 //////)
002423   6900 DMAX(3)=57.296*DMAX(3)
002425        ANCGT=57.296*ANCGT
002426        ANCGT=90.0-ANCGT
002430        THRAT=DMAX(3)/ANCGT
       C      ****************************************************************
       C      PRINT TABULATION OF PEAK RESPONSE PARAMETERS
       C      ****************************************************************
002431        WRITE (5,610) (DMAX(I), I=1,3), DMIN(2)
002445        WRITE(5,619)ANCGT,THRAT
002455        WRITE (5,611) PRMAX
002463    610 FORMAT(/// 32H MAX DISP OF C.G. IN X DIR (IN)=,F10.2,
             1          / 32H MAX DISP OF C.G. IN Y DIR (IN)=,F10.2,
             1          / 32H MAX ROTATION OF STR ( DEGREE) =,F10.2,
             1          / 32H MAX UPLIFT   OF STR        (IN)=,F10.2 )
002463    611 FORMAT(/// 41H MAX SOIL PRESSURE AT THE TOE(PSI)      =,F10.2)
002463        IF(NFCN)613,613,612
002465    612 WRITE(5,616)VMAX,XMMAX,XMAX
002477    616 FORMAT(//20X,16HFCN DESIGN LOADS,/,20X,16H----------------,//,
             1  43H MAX SHEAR AT .15L FROM FACE OF WALL(LB/IN),4X,2H =,F7.1,/,
             241H CORRESPONDING MOMENT AT .15L(IN-LB/IN) =,F10.1,/,
```

```
                3 37H MAX MOMENT AT FACE OF WALL(IN-LB/IN),2X,2H =,F15.1)
002477        615 FORMAT(/ 32H OVERTURNING ANGLE(DEGREES)....=,F10.2,
                1       / 29H RATIO OF MAX ROTATION OF STR,/,
                2          32H TO OVERTURNING ANGLE...........=,F10.2)
002477        613 IF(IC2)696,696,99
           C      *************************************************************
           C      PRINT MESSAGE INDICATING INSUFFICIENT NUMBER OF INTEGRATION TIME
           C      INCREMENTS
           C      *************************************************************
002501         16 WRITE (5,409)
002505        409 FORMAT(/// 23H GIVEN TIME NOT ENOUGH )
002505            IF(IC1) 99,93,99
002506         93 IOTME = IOTME + 1
002510            IF( IOTME -4 ) 96,96,99
002512         96  TW = TW - TW/8.
002515            CALL CGTH2
002516         99 CALL MULTE
002517        300 IF(IOT) 602,604,604
002521        602 DTW = ABS (TW - TWOT)
002524            DTWTW = DTW /TWOT
002525            IF(DTW-2.0)607,607,1707
002527       1707 IF ( DTWTW - 0.025) 607,607,608
002532        608 IOT = 1
002533            TWOT = TW
002535            DTW2 = DTW /2.
002537            TW = TW + DTW2
002540            TS = TW*C9
002542            CALL CGTH2
002543        604 IOT = 1
002544            TWOT = TW
002546            TW = 2.*TW
002547            TS = TW * C9
002551            C8 = TW/B8
002553            SB8= BS /B8
002554            UPLTW = 1. - SB8
002556            IF ( C8 - UPLTW ) 605,606,606
002561        695 WRITE( 5,910)
002565        910 FORMAT(/33H WALL TOO THICK, GO TO NEXT  OINT )
002565            CALL MULTE
002566        605 CALL CGTH2
002567         15 FORMAT(1H1,23X,35A2/)
002567        104 FORMAT( F8.5, 3X, 3E12.4,  17X, 3E12.4 ,5X,E12.4)
002567        202 FORMAT(              19X,21H DISPLACEMENT OF C.G. ,34X,
               117H RESISTING FORCES /)
002567        204 FORMAT(1X,5H TIME,10X,2H X,10X,2H Y,8X,6H THETA,
                1             29X,2H X,10X, 2H Y, 8X,6H THETA,12X,5H XFON)
002567       1007 FORMAT(1X,6H (SEC),8X,4H(IN),8X,4H(IN),8X,5H(DEG),
                1   24X,5H(LBS),7X,5H(LBS),5X,8H(IN-LBS),11X,5H (IN)/)
002567       1900 FORMAT(1X,6H (SEC),9X,11H(IN/SEC**2),1X,11H(IN/SEC**2),1X,12H(RAD/
               1SEC**2),19X,8H(IN/SEC),4X,8H(IN/SEC),3X,9H(RAD/SEC),9X,8H(IN/SEC)/
               2)
002567        205 FORMAT(10X,101HBEARING PRESSURES IN SOIL AT SOIL ELEMENT ATTACHMEN
               1T POINTS FROM LEFT TO RIGHT END OF FOUNDATION(PSI),//,1X,11HELEMEN
               2T NO.,2X,19(I2,6X))
002567       2200 FORMAT(/3X,4HTIME/)
```

```
002567      207 FORMAT( F0.5, 15(2X,F6.1))
002567     1500 FORMAT(///,5X,51HWALL DISINTEGRATES BEFORE STRUCTURE OVERTURNS TIM
               1E ,F10.5/)
002567     1501 FORMAT(/5X,6HDC(IN),29X,F10.2,/,5X,19HREINFORCEMENT RATIO,16X,F10.
               15,/,5X,32HSTEEL DYNAMIC DESIGN STRESS(PSI),3X,F10.1,/,5X,24HULTIMA
               2TE RESISTANCE(PSI),11X,F10.1,/,5X,29HTOTAL IMPULSE ON WALL(PSI-MS)
               3,6X,F10.1,/,5X,29HTIME AT WHICH WALL FAILS(SEC),6X,F10.6)
002567     1502 FORMAT(/5X,6HDC(IN),29X,F10.2,/,5X,24HVERT REINFORCEMENT RATIO,11X
               1,F10.5,/,5X,25HHORIZ REINFORCEMENT RATIO,10X,F10.5,/,5X,25HCRACK L
               2INE LOCATION-Y(IN),10X,F10.2,/,5X,32HSTEEL DYNAMIC DESIGN STRESS(P
               3SI),3X,F10.1,/,5X,24HPLASTIC LOAD MASS FACTOR,11X,F10.3,/,5X,25HUL
               4TIMATE LOAD MASS FAXTOR,10X,F10.3,/,5X,24HULTIMATE RESISTANCE(PSI)
               5,11X,F10.1,/,5X,29HPOST ULTIMATE RESISTANCE(PSI),6X,F10.1)
002567     1503 FORMAT(/5X,6HDC(IN),29X,F10.2,/,5X,24HVERT REINFORCEMENT RATIO,11X
               1,F10.5,/,5X,25HHORIZ REINFORCEMENT RATIO,10X,F10.5,/,5X,25HCRACK L
               2INE LOCATION-X(IN),10X,F10.2,/,5X,32HSTEEL DYNAMIC DESIGN STRESS(P
               3SI),3X,F10.1,/,5X,24HPLASTIC LOAD MASS FACTOR,11X,F10.3,/,5X,25HUL
               4TIMATE LOAD MASS FAXTOR,10X,F10.3,/,5X,24HULTIMATE RESISTANCE(PSI)
               5,11X,F10.1,/,5X,29HPOST ULTIMATE RESISTANCE(PSI),6X,F10.1)
002567     1504 FORMAT(5X,30HPARTIAL FAILURE DEFLECTION(IN),5X,F10.2,/,5X,29HTOTAL
               1 IMPULSE ON WALL(PSI-MS),6X,F10.1,/,5X,29HTIME AT WHICH WALL FAILS
               2(SEC),6X,F10.5)
002567     1505 FORMAT(///,5X,36HWALL REACHES INCIPIENT FAILURE TIME ,F10.5)
002567     1506 FORMAT(5X,31HMAX VELOCITY OF FRAGMENT(INPMS),4X,F10.1)
002567          RETURN
002570          END
```

```
                SUBROUTINE DEDE(IY,XR,AL,SM1,SM2,E1,E2,X,ASPG,XK,YK,NS,HK,VK,U,
               1VX,J,STMP,R,LSIG,S,ALP,BET,XSET,XLAST,XSET1,HLAST,HCONT,H,T5,T,
               1X1,TLAST,ISIG,UM2EL)
000046          DIMENSION IY(15),X(3)     ,XK(15)     ,YK(15)     ,U(15),VX(3)    ,
               1 XSET(15),LSIG(15),XLAST(15),R(3),XSET1(15),S(15)
               2 ,HLAST(15),HCONT(15),T5(15),X1(3),ISIG(15),TLAST(15),UM2EL(15)
          C     ***************************************************************
          C     MONITOR VERTICAL DISPLACEMENTS AND VELOCITIES AT SOIL ELEMENT
          C     ATTACHMENT POINTS ON FOUNDATION TO DETERMINE IF FOUNDATION IS
          C     MOVING UPWARD AWAY FROM THE SOIL
          C     ***************************************************************
000046          DO 1000 I=1,NS
000047          Y=X(2)    + U(I)*SIN(X(3))
000060          YDOT=VX(2)    + U(I)*VX(3)*COS(X(3))
000074          IF(LSIG(I))100,100,500
000103      100 IF(Y)130,125,125
000105      125 IF(YDOT)150,150,200
000107      130 XSET(I)=0.0
000112          GO TO 175
000112      150 XSET(I)=Y
000115      175 XK(I)  =0.0
000117          YK(I)  =0.0
000121          LSIG(I)=1
000124          S(I)=0.0
000126          HCONT(I)=0.0
000130          HLAST(I)=0.0
000132          T5(I)=0.0
000134          ISIG(I)=0.0
000136          TLAST(I)=0.0
000140          UM2EL(I)=0.0
000142          GO TO 1000
000143      200 IF(IY(I))220,220,250
          C     ***************************************************************
          C     COMPUTE NORMAL STRESS IN SOIL ELEMENT FOR FIRST PORTION OF
          C     BILINEAR STRESS STRAIN CURVE
          C     ***************************************************************
000146      220 ALPH=SM1*(1.0+XR/AL)- SM2*XR/AL + E1*VK*X(2)   /ASPG
000157          BETA=(SM2-SM1)/AL   + E1*VK*SIN(X(3))/ASPG
000170          SH=ALPH + BETA*U(I)
000203          S(I)=SH
000206          IF(SH-STMP)226,229,229
000211      229 IY(I)=1
000213          HLAST(I)=X(1)-H*SIN(X(3))
000225          GO TO 250
000231      226 YK(I)   =E1*VK
000234          XK(I)   =E1*HK
000237          R(2)=R(2)+VK(I)*Y + ASPG*(ALP + BET*U(I))
000254          R(3)=R(3)+SH*ASPG*(U(I)*COS(X(3)) -H*SIN(X(3)))
000277          GO TO 1000
          C     ***************************************************************
          C     COMPUTE NORMAL STRESS IN SOIL ELEMENT FOR SECOND PORTION OF
          C     BILINEAR STRESS STRAIN CURVE
          C     ***************************************************************
000303      250 SH=STMP + (Y-XLAST(I))*E2*VK/ASPG
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```
000313          S(I)=SN
000316          XK(I)  =E2*HK
000322          YK(I)=E2*VK
000326          R(2)  =R(2)    + SN*ASPG
000332          R(3)  =R(3)    + SN*ASPG*(U(I)*COS(X(3)) -H*SIN(X(3)))
000353          GO TO 1000
000357      500 IF(Y)550,550,575
000361      550 XK(I)  =0.0
000363          YK(I)  =0.0
000365          S(I)=0.0
000367          IF(XSET1(I))555,555,560
000372      560 XSET(I)=XSET1(I)
000374          XSET1(I)=0.0
000400          HCONT(I)=0.0
000402          TS(I)=0.0
000404          ISIG(I)=0
000406          TLAST(I)=0.0
000410          UMZEL(I)=0.0
000412      555 IF(XSET(I)-XLAST(I))1000,565,565
000420      565 IY(I)=1
000422          HLAST(I)=0.0
000424          GO TO 1000
000425      575 IF(YDOT)550,550,600
000427      600 IF(Y-XSET(I))550,550,650
000434      650 IF(HCONT(I))775,700,775
000437      700 HCONT(I)=X(1)-H*SIN(X(3))
000451          TS(I)=T
000454      775 IF(IY(I))850,850,800
000462      800 IF(E1-E2)825,825,830
000465      825 XK(I)  =E2*HK
000471          YK(I)  =E2*VK
000475          GO TO 900
000475      830 XK(I)=E1*HK
000500          YK(I)=E1*VK
000504          GO TO 900
000504      850 XK(I)  =E1*HK
000507          YK(I)  =E1*VK
000512          IF(Y-XLAST(I))900,900,875
       C        ****************************************************************
       C        COMPUTE NORMAL STRESS IN SOIL ELEMENT AFTER ATTACHMENT POINT
       C        REGAINS CONTACT WITH SOIL
       C        ****************************************************************
000517      875 SN=YK(I)*(XLAST(I)-XSET(I))/ASPG
000527          SN=SN + E2*VK*(Y-XLAST(I))/ASPG
000540          IF(HLAST(I))950,880,950
000543      880 HLAST(I)=X(1)-H*SIN(X(3))
000555          GO TO 950
000561      900 SN=YK(I)  *(Y-XSET(I))/ASPG
000570      950 R(2)  =R(2)   +SN*ASPG
000574          R(3)  =R(3)   +SN*ASPG*(U(I)*COS(X(3)) -H*SIN(X(3)))
000615          XSET1(I)=Y
000620          S(I)=SN
000623     1000 CONTINUE
000632          RETURN
000633          END
```

```
                SUBROUTINE UPCHK(NS,SN,ASPG,XNEU,XNSL,RMAXP,RMAXN,R1,ITYPE,FRICT)
000015          DIMENSION SN(15),RMAXP(15),RMAXN(15),R1(15)
          C     ****************************************************************
          C     COMPUTE FRICTION FORCE ON FOUNDATION
          C     ****************************************************************
000015          XNSL=0.0
000015          DO 20 I=1,NS
000017          IF(SN(I))5,5,10
000021        5 RMAXP(I)=0.0
000023          RMAXN(I)=0.0
000025          R1(I)=0.0
000027          GO TO 20
000030       10 GO TO(12,16),ITYPE
000036       12 XNSL = XNSL + XNEU*ASPG*SN(I)
000042          GO TO 20
000043       16 XNSL = XNSL + FRICT
000045       20 CONTINUE
000050          RETURN
000050          END
```

```
                SUBROUTINE R3(NS,SN,R,H,U,X,XNSL)
000012          DIMENSION SN(15),R(3),U(15),X(3),IAT(15)
000012          NAT=0
           C    *****************************************************************
           C    COMPUTE MOMENT OF HORIZONTAL SOIL RESISTANCE FORCES ABOUT CENTER
           C    OF GRAVITY OF STRUCTURE
           C    *****************************************************************
000013          DO 20 I=1,NS
000014          IF(SN(I))20,20,15
000016       15 NAT=NAT +1
000020          IAT(NAT)=I
000022       20 CONTINUE
000025          RT=XNSL/NAT
000027          DO 50 I=1,NAT
000031          K=IAT(I)
000032          XLEV=U(K)
000035       50 R(3)=R(3) -RT*(H*COS(X(3)) +XLEV*SIN(X(3)))
000061          RETURN
000062          END
```

```
                                        NNVFADN    RUN V2.3  PSR 380   09/26/79  17.52.39

                SUBROUTINE FDN(NS,U,XBP,X15L,SM,VMAX,XMMAX,XMAX,TS)
000014          DIMENSION U(15),SM(15),X(2)
000014          X(1)=X15L
000014          X(2)=XBP
000016          DO 190 K=1,2
000017          V=0.0
000020          XM=0.0
000021          DO 100 I=1,NS
000022          J=NS-I+1
000024          IF(X(K)-U(J-1))20,75,75
         C      ****************************************************************
         C      COMPUTE SHEAR AND CORRESPONDING BENDING MOMENT AT CRITICAL SECTION
         C      FOR SHEAR FOR FOUNDATION EXTENSION OF CANTILEVER WALL BARRIER
         C      ****************************************************************
000031       20 AREA=U(J)-U(J-1)
000034          V=V+.5*(SM(J)+SM(J-1))*AREA
000042          XMM=SM(J-1)*AREA*(U(J-1) + .5*AREA -X(K))
         C      ****************************************************************
         C      COMPUTE BENDING MOMENT AT FACE OF SUPPORT OF FOUNDATION EXTENSION
         C      OF CANTILEVER WALL BARRIER
         C      ****************************************************************
000052          XM =XMM+ (SM(J) -SM(J-1))*.5*AREA*(.666*AREA +U(J-1)-X(K)) +XM
000070          GO TO 100
000071       75 SFACE=(SM(J)-SM(J-1))*(X(K)-U(J-1))/AREA  +SM(J-1)
000101          AREA=U(J)-X(K)
000105          V=V+(SM(J) +SFACE)*.5*AREA
000112          XMM=SFACE*.5*(AREA**2.0)
000117          XM =XMM + (SM(J)-SFACE)*.333*(AREA**2.0)+XM
000131          GO TO 115
000132      100 CONTINUE
000135      115 GO TO(120,150),K
000143      120 IF(V-VMAX)190,190,125
000146      125 VMAX=V
000147          XMMAX=XM
000151          GO TO 190
000152      150 IF(XM-XMAX )190,190,175
000155      175 XMAX=XM
000157      190 CONTINUE
000161          RETURN
000162          END
```

D.3 Sample Problems

Two sample problems are presented. The first problem is the cantilever wall barrier that was analyzed in Appendix C. The configuration of the structure is shown in Figure C.13. The input data are given in Figures D.1 through D.4. Immediately following the figures is a portion of the printed output of the analysis.

The second problem is the single cell barrier that was analyzed in Appendix C. The configuration of the structure is shown in Figures C.16 and C.17. The input is given in Figures D.5 through D.22. A portion of the printed output of the analysis is presented on pages 236 through 249.

CARD TYPE 1

Problem Identification (Title Card)
2 EXAMPLE PROBLEM D.1 CANTILEVER WALL BARRIER ON COMPACT GRAVEL 71

CARD TYPE 2

1 5	6 10	11 15	16 20		26 30	31 35	36 40	41 45	46 50	51 55	56 60	61 65
NP	N	NS	NUMTM		ICI	ICAI	NDEL2	NUMPT	NWALL	NVEL	NFDN	NLOAD
3	1	10	5000		1	0	1	20	1	1	1	0

Figure D.1 Input data sheet - Example D.1: Card Types 1 and 2.

CARD TYPE 3

1 10	11 20	21 30	31 40	41 50	51 60	61 70
SOIL MODULUS E1	SOIL MODULUS E2	STRESS AT WHICH MODULUS CHANGES	COEFFICIENT OF FRICTION	POISSON'S RATIO	β_x	β_z
(PSI)	(PSI)	(PSI)				
20000.0	20000.0	2000.0	.7	.15	1.0	2.0

CARD TYPE 4

1 10	11 20	21 30	31 40	41 50	51 60	61 70
BACKWALL THICKNESS (TW)	C9	LENGTH OF BACKWALL (CL)	HEIGHT OF BACKWALL (FT)	SSB	HB	WIDTH OF HAUNCH (HAUNH)
(IN)		FT	FT			IN
75.0	1.253	52.0	16.25	.353	.765	12.0

Figure D.2 Input data sheet - Example D.1: Card Types 3 and 4.

CARD TYPE 5 - Charge No. 1

1 10	11 20	21 30	31 40	41 50	51 60	61 70
RA	W	XI (1)	XI (2)	XI (3)	CL2	H
(FT)	LBS	PSI-MS	PSI-MS	PSI-MS	FT	FT
6.875	2280.0	3400.0	4400.0	0.0	14.5	3.0

CARD TYPE 5 - Charge No. 2

1 10	11 20	21 30	31 40	41 50	51 60	61 70
RA	W	XI (1)	XI (2)	XI (3)	CL2	H
(FT)	LBS	PSI-MS	PSI-MS	PSI-MS	FT	FT
6.875	2280.0	3100.0	4800.0	0.0	26.0	3.0

Figure D.3 Input data sheet - Example D.1: Card Type 5.

CARD TYPE 5 -Charge No. 3

1 10	11 20	21 30	31 40	41 50	51 60	61 70
RA	W	XI (1)	XI (2)	XI (3)	CL2	H
(FT)	LBS	PSI-MS	PSI-MS	PSI-MS	FT	FT
6.875	2280.0	3400.0	4400.0	0.0	14.5	3.0

CARD TYPE 7

1 10	11 20	21 30	31 40	41 45	46 50	51 60	61 70	71 80
XI	DC	p_v	p_h	x	y	FDS	$(KLM)_q$	VF
PSI-MS	IN			IN	IN	PSI		IN/MS
9900.0	68.0	.00570				90000.0		

Figure D.4 Input data sheet - Example D.1: Card Types 5 and 7.

EXAMPLE PROBLEM D.1 CANTILEVER WALL BARRIER ON COMPACT GRAVEL

NUMBER OF CHARGES	3
NUMBER OF WALLS	1
NUMBER OF SOIL SPRINGS	10
NUMBER OF TIME INCREMENTS	5000
LEAST TIME OF ARRIVAL OF BLAST TO NEAREST POINT(SEC)	.00006
LEAST DURATION TIME(SEC)	.00535
PRINT FREQUENCY	20
INTEGRATION TIME INTERVAL 1(SEC)	2.67494E-04
INTEGRATION TIME INTERVAL 2(SEC)	2.67494E-04

SOIL PROPERTIES

MODULUS OF ELASTICITY E1(PSI)	20000.00
MODULUS OF ELASTICITY E2(PSI)	20000.00
NORMAL STRESS AT WHICH MODULUS CHANGES(PSI)	2000.00
COEFFICIENT OF FRICTION	.70
POISSONS RATIO	.15
SHAPE FACTOR BX	1.00
SHAPE FACTOR BY	2.00
KH1/SPRING(LB/IN)	797794.02
KV1/SPRING(LB/IN)	816158.30
KH2/SPRING(LB/IN)	797794.02
KV2/SPRING(LB/IN)	816158.30
KH1 TOTAL(LB/IN)	7977940.19
KV1 TOTAL(LB/IN)	8161583.02
KH2 TOTAL(LB/IN)	7977940.19
KV2 TOTAL(LB/IN)	8161583.02

STRUCTURE GEOMETRY

BACKWALL THICKNESS(IN)	75.000
RATIO OF SLAB THICKNESS TO BACKWALL THICKNESS	1.253
LENGTH OF BACKWALL(FT)	52.000
HEIGHT OF BACKWALL(FT)	16.250
RATIO OF WIDTH OF FLOOR TO TOTAL WIDTH OF BASE	.351
RATIO OF HEIGHT OF WALL TO BASE OF STRUCTURE	.765
WIDTH OF BASE(IN)	254.9463
WIDTH OF LOADED AREA ON BASE(IN)	89.999
SLAB THICKNESS(IN)	94.000
RATIO OF WALL THICKNESS TO WIDTH OF STRUCTURE	.294
HORIZONTAL DISTANCE FROM CG TO REAR FACE OF WALL(IN)	-37.500
VERTICAL DISTANCE FROM TOP OF FLOOR SLAB TO CG(IN)	7.756
DISTANCE FROM CG TO REAR END OF SLAB(IN)	-127.499
MASS(LB-SEC**2/IN)	5615.9
MASS MOMENT OF INERTIA(LB-IN-SEC**2)	6.47827E+07
WEIGHT(LBS)	2.09856E+06

EXAMPLE PROBLEM D.1 CANTILEVER WALL BARRIER ON COMPACT GRAVEL

LOADING

CHARGE NUMBER 1

MIN DISTANCE FROM CHARGE TO WALL(FT)	6.875
CHARGE WEIGHT(LBS)	2200.0
IMPULSE ON WALL(PSI-MS)	3400.0
IMPULSE ON FLOOR(PSI-MS)	4400.0
MIN DISTANCE FROM CHARGE TO EDGE OF WALL(FT)	14.500
HEIGHT OF CHARGE ABOVE FLOOR SLAB(FT)	3.000

AREA OF FACE(IN**2)	121600.0
HORIZONTAL DISTANCE FROM CENTROID OF AREA TO CG(IN)	-37.5
VERTICAL DISTANCE FROM CENTROID OF AREA TO CG(IN)	-89.7

PRESSURE TIME CURVE

POINT 1 PRESSURE(PSI) 895.1 TIME(SEC) .00032
POINT 2 PRESSURE(PSI) .0 TIME(SEC) .00791

	TIME (SEC)	FORCE X (LBS)	FORCE Y (LBS)	MOMENT ABOUT Z (IN-LBS)
2	.00033	1.0870E+08	.0	9.7549E+09
3	.00060	1.0406E+08	.0	9.4107E+09
4	.00087	1.0103E+08	.0	9.0665E+09
5	.00113	9.7191E+07	.0	8.7223E+09
6	.00140	9.3356E+07	.0	8.3781E+09
7	.00167	8.9528E+07	.0	8.0339E+09
8	.00194	8.5685E+07	.0	7.6897E+09
9	.00220	8.1858E+07	.0	7.3455E+09
10	.00247	7.8015E+07	.0	7.0013E+09
11	.00274	7.4179E+07	.0	6.6571E+09
12	.00301	7.0344E+07	.0	6.3129E+09
13	.00327	6.6509E+07	.0	5.9687E+09
14	.00354	6.2673E+07	.0	5.6245E+09
15	.00381	5.8838E+07	.0	5.2803E+09
16	.00408	5.5003E+07	.0	4.9362E+09
17	.00434	5.1167E+07	.0	4.5920E+09
18	.00461	4.7332E+07	.0	4.2478E+09
19	.00488	4.3497E+07	.0	3.9036E+09
20	.00515	3.9662E+07	.0	3.5594E+09
21	.00541	3.5826E+07	.0	3.2152E+09
22	.00568	3.1991E+07	.0	2.8710E+09
23	.00595	2.8156E+07	.0	2.5268E+09
24	.00622	2.4320E+07	.0	2.1826E+09
25	.00648	2.0485E+07	.0	1.8384E+09
26	.00675	1.6650E+07	.0	1.4942E+09
27	.00702	1.2815E+07	.0	1.1500E+09
28	.00729	8.9793E+06	.0	8.0583E+08
29	.00755	5.1440E+06	.0	4.6164E+08
30	.00782	1.3087E+06	.0	1.1745E+08

AREA OF FACE(IN**2)	58159.9
HORIZONTAL DISTANCE FROM CENTROID OF AREA TO CG(IN)	-82.5
VERTICAL DISTANCE FROM CENTROID OF AREA TO CG(IN)	7.0

PRESSURE TIME CURVE

POINT 1 PRESSURE(PSI) 1236.0 TIME(SEC) .00006
POINT 2 PRESSURE(PSI) .0 TIME(SEC) .00710

	TIME (SEC)	FORCE X (LBS)	FORCE Y (LBS)	MOMENT ABOUT Z (IN-LBS)
1	.00006	.0	6.9460E+07	-5.7304E+09
2	.00033	.0	6.6849E+07	-5.5150E+09
3	.00060	.0	6.4237E+07	-5.2996E+09
4	.00087	.0	6.1626E+07	-5.0841E+09
5	.00113	.0	5.9014E+07	-4.8687E+09
6	.00140	.0	5.6403E+07	-4.6532E+09
7	.00167	.0	5.3792E+07	-4.4378E+09
8	.00194	.0	5.1180E+07	-4.2223E+09
9	.00220	.0	4.8569E+07	-4.0069E+09
10	.00247	.0	4.5957E+07	-3.7915E+09
11	.00274	.0	4.3346E+07	-3.5760E+09
12	.00301	.0	4.0734E+07	-3.3606E+09
13	.00327	.0	3.8123E+07	-3.1451E+09
14	.00354	.0	3.5512E+07	-2.9297E+09
15	.00381	.0	3.2900E+07	-2.7142E+09
16	.00408	.0	3.0289E+07	-2.4988E+09
17	.00434	.0	2.7677E+07	-2.2834E+09
18	.00461	.0	2.5066E+07	-2.0679E+09
19	.00488	.0	2.2454E+07	-1.8525E+09
20	.00515	.0	1.9843E+07	-1.6370E+09
21	.00541	.0	1.7231E+07	-1.4216E+09
22	.00568	.0	1.4620E+07	-1.2061E+09
23	.00595	.0	1.2009E+07	-9.9071E+08
24	.00622	.0	9.3972E+06	-7.7526E+08
25	.00648	.0	6.7857E+06	-5.5982E+08
26	.00675	.0	4.1743E+06	-3.4438E+08
27	.00702	.0	1.5629E+06	-1.2894E+08

EXAMPLF PROBLEM D.1 CANTILEVER WALL BARRIER ON COMPACT GRAVEL

LOADING

CHARGE NUMBER 2

MIN DISTANCE FROM CHARGE TO WALL(FT)	6.075
CHARGE WEIGHT(LBS)	2200.0
IMPULSE ON WALL(PSI-MS)	3100.0
IMPULSE ON FLOOR(PSI-MS)	4800.0
MIN DISTANCE FROM CHARGE TO EDGE OF WALL(FT)	26.000
HEIGHT OF CHARGE ABOVE FLOOR SLAB(FT)	3.000

AREA OF FACE(IN**2)	121600.0
HORIZONTAL DISTANCE FROM CENTROID OF AREA TO CG(IN)	-37.5
VERTICAL DISTANCE FROM CENTROID OF AREA TO CG(IN)	-89.7

PRESSURE TIME CURVE

POINT 1 PRESSURE(PSI) 1020.3 TIME(SEC) .00032
POINT 2 PRESSURE(PSI) .0 TIME(SEC) .00639

	TIME (SEC)	FORCE X (LBS)	FORCE Y (LBS)	MOMENT ABOUT Z (IN-LBS)
2	.00033	1.2303E+08	.0	1.1113E+10
3	.00060	1.1836E+08	.0	1.0622E+10
4	.00087	1.1290E+08	.0	1.0132E+10
5	.00113	1.0743E+08	.0	9.6415E+09
6	.00140	1.0197E+08	.0	9.1511E+09
7	.00167	9.6504E+07	.0	8.6607E+09
8	.00194	9.1040E+07	.0	8.1702E+09
9	.00220	8.5575E+07	.0	7.6798E+09
10	.00247	8.0110E+07	.0	7.1894E+09
11	.00274	7.4646E+07	.0	6.6990E+09
12	.00301	6.9181E+07	.0	6.2086E+09
13	.00327	6.3716E+07	.0	5.7182E+09
14	.00354	5.8252E+07	.0	5.2277E+09
15	.00381	5.2787E+07	.0	4.7373E+09
16	.00408	4.7323E+07	.0	4.2469E+09
17	.00434	4.1858E+07	.0	3.7565E+09
18	.00461	3.6393E+07	.0	3.2661E+09
19	.00488	3.0929E+07	.0	2.7757E+09
20	.00515	2.5464E+07	.0	2.2852E+09
21	.00541	1.9999E+07	.0	1.7948E+09
22	.00568	1.4535E+07	.0	1.3044E+09
23	.00595	9.0701E+06	.0	8.1398E+08
24	.00622	3.6094E+06	.0	3.2357E+08

AREA OF FACE(IN**2)	54159.5
HORIZONTAL DISTANCE FROM CENTROID OF AREA TO CG(IN)	-82.9
VERTICAL DISTANCE FROM CENTROID OF AREA TO CG(IN)	7.0

PRESSURE TIME CURVE

POINT 1 PRESSURE(PSI) 1794.4 TIME(SEC) .00086
POINT 2 PRESSURE(PSI) .0 TIME(SEC) .00541

	TIME (SEC)	FORCE X (LBS)	FORCE Y (LBS)	MOMENT ABOUT Z (IN-LBS)
1	.00006	.0	1.0077E+08	-8.3139E+09
2	.00033	.0	9.5736E+07	-7.8982E+09
3	.00060	.0	9.5647E+07	-7.4825E+09
4	.00087	.0	8.5658E+07	-7.0668E+09
5	.00113	.0	8.0620E+07	-6.6511E+09
6	.00140	.0	7.5581E+07	-6.2354E+09
7	.00167	.0	7.0542E+07	-5.8197E+09
8	.00194	.0	6.5503E+07	-5.4040E+09
9	.00220	.0	6.0465E+07	-4.9883E+09
10	.00247	.0	5.5426E+07	-4.5726E+09
11	.00274	.0	5.0387E+07	-4.1569E+09
12	.00301	.0	4.5349E+07	-3.7412E+09
13	.00327	.0	4.0310E+07	-3.3255E+09
14	.00354	.0	3.5271E+07	-2.9099E+09
15	.00381	.0	3.0232E+07	-2.4942E+09
16	.00408	.0	2.5194E+07	-2.0785E+09
17	.00434	.0	2.0155E+07	-1.6628E+09
18	.00461	.0	1.5116E+07	-1.2471E+09
19	.00488	.0	1.0077E+07	-8.3139E+08
20	.00515	.0	5.0387E+06	-4.1569E+08
21	.00541	.0	8.1723E-07	-6.7421E-05

THE PRINTED OUTPUT CONTAINING THE LOAD TIME HISTORIES FOR CHARGE NUMBER 3 HAS BEEN OMITTED.

EXAMPLE PROBLEM D.1 CANTILEVER WALL BARRIER ON COMPACT GRAVEL

LOADING

	TIME (SEC)	FORCE X (LBS)	FORCE Y (LBS)	MOMENT ABOUT Z (IN-LBS)
1	.00006	.0	2.3969E+08	-1.9775E+10
2	.00033	3.4122E+08	2.2943E+08	1.1694E+10
3	.00060	3.2809E+08	2.1917E+08	1.1362E+10
4	.00087	3.1495E+08	2.0891E+08	1.1030E+10
5	.00113	3.0182E+08	1.9865E+08	1.0698E+10
6	.00140	2.8868E+08	1.8839E+08	1.0365E+10
7	.00167	2.7555E+08	1.7813E+08	1.0033E+10
8	.00194	2.6241E+08	1.6786E+08	9.7009E+09
9	.00220	2.4927E+08	1.5760E+08	9.3687E+09
10	.00247	2.3614E+08	1.4734E+08	9.0365E+09
11	.00274	2.2300E+08	1.3708E+08	8.7043E+09
12	.00301	2.0987E+08	1.2682E+08	8.3720E+09
13	.00327	1.9673E+08	1.1656E+08	8.0398E+09
14	.00354	1.8360E+08	1.0629E+08	7.7076E+09
15	.00381	1.7046E+08	9.6033E+07	7.3754E+09
16	.00408	1.5733E+08	8.5771E+07	7.0431E+09
17	.00434	1.4419E+08	7.5509E+07	6.7109E+09
18	.00461	1.3106E+08	6.5248E+07	6.3787E+09
19	.00488	1.1792E+08	5.4986E+07	6.0465E+09
20	.00515	1.0479E+08	4.4725E+07	5.7142E+09
21	.00541	9.1652E+07	3.4463E+07	5.3820E+09
22	.00568	7.8517E+07	2.9240E+07	4.6341E+09
23	.00595	6.5382E+07	2.4017E+07	3.8862E+09
24	.00622	5.2246E+07	1.8794E+07	3.1383E+09
25	.00648	4.0978E+07	1.3571E+07	2.5572E+09
26	.00675	3.3300E+07	8.3606E+06	2.2997E+09
27	.00702	2.5629E+07	3.1257E+06	2.0422E+09
28	.00729	1.7959E+07	.0	1.6117E+09
29	.00755	1.0288E+07	.0	9.2320E+08
30	.00782	2.6174E+06	.0	2.3409E+08

FORCE VECTOR EQUALS ZERO AFTER TIME .0076.

WALL REACHES INCIPIENT FAILURE TIME .07951

EXAMPLE PROBLEM D.1 CANTILEVER WALL BARRIER ON COMPACT GRAVEL

DC(IN)	68.00
REINFORCEMENT RATIO	.00578
STEEL DYNAMIC DESIGN STRESS(PSI)	90000.0
ULTIMATE RESISTANCE(PSI)	124.8
TOTAL IMPULSE ON WALL(PSI-MS)	9900.0
TIME AT WHICH WALL FAILS(SEC)	.079349

EXAMPLE PROBLEM D.1 CANTILEVER WALL BARRIER ON COMPACT GRAVEL

	DISPLACEMENT OF C.G.			RESISTING FORCES			
TIME (SEC)	X (IN)	Y (IN)	THETA (DEG)	X (LBS)	Y (LBS)	THETA (IN-LBS)	XFDN (IN)
.00006	.0	.0	.0	.0	2.0986E+06	.0	.0
.00541	6.7195E-01	4.5098E-01	1.3171E-01	3.4947E+06	5.7713E+06	-2.3270E+08	4.3804E-01
.01076	1.8822E+00	1.1008E+00	4.1412E-01	8.2049E+06	1.1721E+07	-4.5283E+08	1.1467E+00
.01611	3.0637E+00	1.8618E+00	7.1551E-01	1.1880E+07	1.6856E+07	-4.9444E+08	1.7938E+00
.02146	4.1826E+00	2.4651E+00	1.0321E+00	1.4771E+07	2.1101E+07	-4.5564E+08	2.3497E+00
.02681	5.2224E+00	2.9667E+00	1.3641E+00	1.7813E+07	2.5447E+07	-5.1003E+08	2.8000E+00
.03216	6.1698E+00	3.3473E+00	1.7095E+00	1.9481E+07	2.7830E+07	-3.6135E+08	3.1343E+00
.03751	7.0157E+00	3.5937E+00	2.0646E+00	2.0195E+07	2.8850E+07	-1.5405E+08	3.3497E+00
.04286	7.7558E+00	3.6992E+00	2.4245E+00	1.9858E+07	2.8368E+07	8.4060E+07	3.4505E+00
.04821	8.3879E+00	3.6633E+00	2.7831E+00	1.7818E+07	2.6269E+07	3.6974E+08	3.4472E+00
.05356	8.9215E+00	3.4923E+00	3.1332E+00	1.7539E+07	2.7404E+07	4.8298E+08	3.3598E+00
.05891	9.3691E+00	3.1977E+00	3.4671E+00	1.3912E+07	2.3141E+07	7.2828E+08	3.2153E+00
.06426	9.7478E+00	2.7984E+00	3.7796E+00	9.7300E+06	1.7180E+07	7.8781E+08	3.0390E+00
.06961	1.0073E+01	2.3192E+00	4.0685E+00	5.0844E+06	9.4847E+06	5.7572E+08	2.8539E+00
.07496	1.0367E+01	1.7916E+00	4.3387E+00	4.9371E+06	9.5436E+06	5.9128E+08	2.6693E+00
.08031	1.0640E+01	1.2329E+00	4.5942E+00	-7.8951E+02	1.1279E+03	2.2229E+05	2.4891E+00
.08566	1.0898E+01	6.8878E-01	4.8481E+00	-7.0079E+03	1.0011E+04	1.9718E+06	2.3096E+00
.09101	1.1179E+01	1.3961E-01	5.1019E+00	-1.9305E+04	2.7578E+04	5.4282E+06	2.1305E+00
.09636	1.1449E+01	-3.9867E-01	5.3555E+00	-3.7490E+04	5.3557E+04	1.0534E+07	1.9519E+00
.10171	1.1720E+01	-9.1816E-01	5.6085E+00	-6.1286E+04	8.7551E+04	1.7289E+07	1.7743E+00
.10706	1.1998E+01	-1.4191E+00	5.8617E+00	-9.8332E+04	1.2905E+05	2.5346E+07	1.5981E+00
.11241	1.2261E+01	-1.9177E+00	6.1130E+00	-1.2419E+05	1.7741E+05	3.4820E+07	1.4239E+00
.11776	1.2533E+01	-2.4061E+00	6.3640E+00	-1.6235E+05	2.3193E+05	4.5486E+07	1.2525E+00
.12311	1.2805E+01	-2.8848E+00	6.6144E+00	-2.0425E+05	2.9178E+05	5.7179E+07	1.0845E+00
.12846	1.3079E+01	-3.3539E+00	6.8623E+00	-2.4929E+05	3.5607E+05	6.9722E+07	9.2006E-01
.13381	1.3354E+01	-3.8139E+00	7.1082E+00	-2.9669E+05	4.2384E+05	8.2926E+07	7.6244E-01
.13916	1.3631E+01	-4.2658E+00	7.3515E+00	-3.4586E+05	4.9409E+05	9.6592E+07	6.1019E-01
.14451	1.3909E+01	-4.7074E+00	7.5920E+00	-3.9684E+05	5.6577E+05	1.1052E+08	4.6511E-01
.14986	1.4169E+01	-5.1424E+00	7.8292E+00	-4.4649E+05	6.3784E+05	1.2449E+08	3.2817E-01
.15521	1.4472E+01	-5.5694E+00	8.0626E+00	-4.9646E+05	7.0923E+05	1.3831E+08	2.0038E-01
.16056	1.4758E+01	-5.9891E+00	8.2919E+00	-5.4523E+05	7.7890E+05	1.5177E+08	8.2724E-02
.16591	1.5046E+01	-6.4019E+00	8.5167E+00	-5.9288E+05	8.4583E+05	1.6467E+08	-2.3838E-02
.17126	1.5337E+01	-6.8091E+00	8.7365E+00	-6.3633E+05	9.0905E+05	1.7683E+08	-1.1839E-01
.17661	1.5632E+01	-7.2088E+00	8.9510E+00	-6.7735E+05	9.6764E+05	1.8807E+08	-2.0007E-01
.18196	1.5930E+01	-7.6028E+00	9.1599E+00	-7.1453E+05	1.0208E+06	1.9823E+08	-2.6809E-01
.18731	1.6233E+01	-7.9913E+00	9.3629E+00	-7.4735E+05	1.0676E+06	2.0717E+08	-3.2173E-01
.19266	1.6539E+01	-8.3733E+00	9.5597E+00	-7.7534E+05	1.1076E+06	2.1476E+08	-3.6035E-01
.19801	1.6849E+01	-8.7518E+00	9.7506E+00	-7.9811E+05	1.1402E+06	2.2089E+08	-3.8343E-01
.20336	1.7163E+01	-9.1237E+00	9.9338E+00	-8.1533E+05	1.1648E+06	2.2549E+08	-3.9855E-01
.20871	1.7482E+01	-9.4915E+00	1.0111E+01	-8.0805E+05	1.1811E+06	2.2619E+08	-3.8142E-01
.21406	1.7805E+01	-9.8545E+00	1.0281E+01	-7.8780E+05	1.1892E+06	2.2439E+08	-3.5604E-01
.21941	1.8132E+01	-1.0212E+01	1.0445E+01	8.4402E+02	1.2057E+03	2.4969E+04	-3.1677E-01
.22476	1.8459E+01	-1.0559E+01	1.0609E+01	7.1792E+03	1.0256E+04	2.0658E+05	-2.7557E-01
.23011	1.8788E+01	-1.0895E+01	1.0773E+01	1.9675E+04	2.8108E+04	5.5024E+05	-2.3425E-01
.23546	1.9112E+01	-1.1228E+01	1.0[illegible]37E+01	3.8264E+04	5.4663E+04	1.0392E+06	-1.9286E-01
.24081	1.9439E+01	-1.1535E+01	1.1[illegible]0E+01	6.2845E+04	8.9779E+04	1.6559E+06	-1.5146E-01
.24616	1.9765E+01	-1.1838E+01	1.1264E+01	9.3288E+04	1.3327E+05	2.3826E+06	-1.1814E-01
.25151	2.0091E+01	-1.2132E+01	1.1427E+01	1.2943E+05	1.8491E+05	3.2010E+06	-6.9036E-02

THE PRINTED OUTPUT CONTAINING THE REMAINDER OF THE DISPLACEMENT TIME HISTORIES HAS BEEN OMITTED.

EXAMPLE PROBLEM D.1 CANTILEVER WALL BARRIER ON COMPACT GRAVEL

	ACCELERATION OF C.G.			VELOCITY OF C.G.			
TIME (SEC)	X (IN/SEC**2)	Y (IN/SEC**2)	THETA (RAD/SEC**2)	X (IN/SEC)	Y (IN/SEC)	THETA (RAD/SEC)	XFDN (IN/SEC)
.00386	1.0501E+04	2.2086E+04	-8.4745E+01	.0	.0	.0	.0
.00541	1.4277E+04	5.6836E+03	1.0249E+02	2.1090E+02	1.3328E+02	7.9299E-01	1.3021E+02
.01076	-1.9158E+03	-1.7782E+03	8.2660E+00	2.2573E+02	1.3333E+02	9.5848E-01	1.2821E+02
.01611	-2.1707E+03	-2.7264E+03	9.0255E+00	2.1587E+02	1.2132E+02	1.0059E+00	1.1352E+02
.02146	-2.7273E+03	-3.5101E+03	8.3172E+00	2.0253E+02	1.0433E+02	1.0587E+00	9.4826E+01
.02681	-3.2696E+03	-4.3125E+03	9.3180E+00	1.8640E+02	8.3454E+01	1.1059E+00	7.3973E+01
.03216	-3.5976E+03	-4.7525E+03	6.5960E+00	1.6834E+02	5.9611E+01	1.1434E+00	5.2043E+01
.03751	-3.7288E+03	-4.9408E+03	2.0128E+00	1.4802E+02	3.3793E+01	1.1676E+00	3.0891E+01
.04286	-3.6666E+03	-4.8519E+03	-1.5344E+00	1.2876E+02	7.1932E+00	1.1746E+00	9.3460E+00
.04821	-3.2699E+03	-4.4643E+03	-6.7493E+00	1.0895E+02	-1.9221E+01	1.1631E+00	-9.2619E+00
.05356	-3.2365E+03	-4.6739E+03	-8.8163E+00	9.1463E+01	-4.3677E+01	1.1216E+00	-2.2497E+01
.05891	-2.5607E+03	-3.8867E+03	-1.1294E+01	7.7048E+01	-6.4876E+01	1.0571E+00	-3.0319E+01
.06426	-1.7965E+03	-2.7861E+03	-1.4301E+01	6.5757E+01	-8.2112E+01	9.8289E-01	-3.4041E+01
.06961	-9.3878E+02	-1.3653E+03	-1.8509E+01	5.7581E+01	-9.4777E+01	9.1130E-01	-3.4925E+01
.07496	-9.1159E+02	-1.3761E+03	-1.0793E+01	5.2628E+01	-1.0211E+02	8.5430E-01	-3.4062E+01
.08031	1.4577E-01	3.0579E+02	-4.0577E-03	5.0446E+01	-1.0429E+02	8.2030E-01	-3.3568E+01
.08566	1.2935E+00	3.4415E+02	-3.5994E-02	5.0449E+01	-1.0223E+02	8.2821E-01	-3.3525E+01
.09101	3.5846E+00	3.8891E+02	-9.9085E-02	5.0461E+01	-1.0018E+02	8.2707E-01	-3.3446E+01
.09636	4.9221E+00	3.7611E+02	-1.9229E-01	5.0488E+01	-9.8158E+01	8.2712E-01	-3.3308E+01
.10171	1.1316E+01	3.6903E+02	-3.1412E-01	5.0536E+01	-9.6162E+01	8.2579E-01	-3.3091E+01
.10706	1.6679E+01	3.6217E+02	-4.6267E-01	5.0618E+01	-9.4202E+01	8.2374E-01	-3.2773E+01
.11241	2.2938E+01	3.5324E+02	-6.3561E-01	5.0715E+01	-9.2286E+01	8.2084E-01	-3.2336E+01
.11776	2.9977E+01	3.4318E+02	-8.3029E-01	5.0855E+01	-9.0422E+01	8.1695E-01	-3.1763E+01
.12311	3.7712E+01	3.3213E+02	-1.0437E+00	5.1035E+01	-8.8613E+01	8.1198E-01	-3.1039E+01
.12846	4.6821E+01	3.2026E+02	-1.2727E+00	5.1[illegible]7E+01	-8.6867E+01	8.0582E-01	-3.0152E+01
.13381	5.4780E+01	3.0774E+02	-1.5137E+00	5.1526E+01	-8.5185E+01	7.9840E-01	-2.9092E+01
.13916	6.3060E+01	2.9477E+02	-1.7632E+00	5.1842E+01	-8.3571E+01	7.8967E-01	-2.7852E+01
.14451	7.3125E+01	2.8154E+02	-2.0173E+00	5.2207E+01	-8.2028E+01	7.7959E-01	-2.6426E+01
.14986	8.2461E+01	2.6823E+02	-2.2724E+00	5.2622E+01	-8.0555E+01	7.6315E-01	-2.4814E+01
.15521	9.1667E+01	2.5585E+02	-2.5247E+00	5.3086E+01	-7.9154E+01	7.5535E-01	-2.3016E+01
.16056	1.0067E+02	2.4210E+02	-2.7734E+00	5.3600E+01	-7.7822E+01	7.4122E-01	-2.1035E+01
.16591	1.0932E+02	2.2983E+02	-3.0059E+00	5.4160E+01	-7.6558E+01	7.2579E-01	-1.8879E+01
.17126	1.1769E+02	2.1015E+02	-3.2279E+00	5.4766E+01	-7.5359E+01	7.0914E-01	-1.6556E+01
.17661	1.2587E+02	2.0734E+02	-3.4331E+00	5.5414E+01	-7.4228E+01	6.9134E-01	-1.4077E+01
.18196	1.3193E+02	1.9753E+02	-3.6186E+00	5.6101E+01	-7.3136E+01	6.7249E-01	-1.1457E+01
.18731	1.3799E+02	1.8807E+02	-3.7817E+00	5.6823E+01	-7.2102E+01	6.5271E-01	-8.7098E+00
.19266	1.4316E+02	1.8145E+02	-3.9202E+00	5.7575E+01	-7.1111E+01	6.3212E-01	-5.8539E+00
.19801	1.4730E+02	1.7548E+02	-4.0322E+00	5.8352E+01	-7.0156E+01	6.1085E-01	-2.9081E+00
.20336	1.4654E+02	1.7094E+02	-4.1161E+00	5.9149E+01	-6.9229E+01	5.8905E-01	1.0771E-01
.20871	1.4920E+02	1.6791E+02	-4.1209E+00	5.9952E+01	-6.8323E+01	5.6698E-01	3.1542E+00
.21406	1.4546E+02	1.6643E+02	-4.0960E+00	6.0741E+01	-6.7429E+01	5.4495E-01	6.1796E+00
.21941	-1.5584E-01	3.8574E+02	-4.5578E-04	6.1127E+01	-6.5952E+01	5.3403E-01	7.6867E+00
.22476	-1.1256E+00	3.8411E+02	-3.7709E-03	6.1124E+01	-6.3891E+01	5.3402E-01	7.7127E+00
.23011	-3.6378E+00	3.8601E+02	-1.8044E-02	6.1111E+01	-6.1844E+01	5.3399E-01	7.7325E+00
.23546	-7.6650E+00	3.7591E+02	-1.8969E-02	6.1084E+01	-5.9819E+01	5.3391E-01	7.7416E+00
.24081	-1.1640E+01	3.6962E+02	-3.0226E-02	6.1035E+01	-5.7823E+01	5.3378E-01	7.7353E+00
.24616	-1.7225E+01	3.6134E+02	-4.3491E-02	6.0959E+01	-5.5867E+01	5.3359E-01	7.7089E+00
.25151	-2.3899E+01	3.5186E+02	-5.8432E-02	6.0850E+01	-5.3957E+01	5.3332E-01	7.6577E+00

THE PRINTED OUTPUT CONTAINING THE REMAINDER OF THE ACCELERATION AND VELOCITY TIME HISTORIES HAS BEEN OMITTED.

EXAMPLE PROBLEM D.1 CANTILEVER WALL BARRIER ON COMPACT GRAVEL

BEARING PRESSURES IN SOIL AT SOIL ELEMENT ATTACHMENT POINTS FROM LEFT TO RIGHT END OF FOUNDATION(PSI)

ELEMENT NO.	1	2	3	4	5	6	7	8	9	10
TIME										
.00006	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1
.00541	21.2	24.6	27.9	31.3	34.6	37.9	41.3	44.6	48.0	51.3
.01076	26.4	36.9	47.4	57.9	68.4	78.9	89.4	99.9	110.4	120.9
.01611	.0	45.1	63.3	81.4	99.6	117.7	135.9	154.0	172.2	190.3
.02146	.0	.0	74.1	100.3	126.5	152.7	178.9	205.0	231.2	257.4
.02681	.0	.0	78.8	113.4	148.0	182.6	217.2	251.8	286.4	321.0
.03216	.0	.0	.0	119.8	163.2	206.5	249.9	293.2	336.6	379.9
.03751	.0	.0	.0	.0	171.3	223.6	276.0	328.4	380.7	433.1
.04286	.0	.0	.0	.0	.0	233.6	295.1	356.6	418.0	479.5
.04821	.0	.0	.0	.0	.0	.0	306.4	377.4	448.0	518.6
.05356	.0	.0	.0	.0	.0	.0	311.4	390.8	470.3	549.7
.05891	.0	.0	.0	.0	.0	.0	.0	396.9	484.8	572.7
.06426	.0	.0	.0	.0	.0	.0	.0	.0	491.9	587.7
.06961	.0	.0	.0	.0	.0	.0	.0	.0	.0	596.1
.07496	.0	.0	.0	.0	.0	.0	.0	.0	.0	599.8
.08031	.0	.0	.0	.0	.0	.0	.0	.0	.0	.1
.08566	.0	.0	.0	.0	.0	.0	.0	.0	.0	.6
.09101	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.7
.09636	.0	.0	.0	.0	.0	.0	.0	.0	.0	3.4
.10171	.0	.0	.0	.0	.0	.0	.0	.0	.0	5.5
.10706	.0	.0	.0	.0	.0	.0	.0	.0	.0	8.1
.11241	.0	.0	.0	.0	.0	.0	.0	.0	.0	11.1
.11776	.0	.0	.0	.0	.0	.0	.0	.0	.0	14.6
.12311	.0	.0	.0	.0	.0	.0	.0	.0	.0	18.3
.12846	.0	.0	.0	.0	.0	.0	.0	.0	.0	22.4
.13381	.0	.0	.0	.0	.0	.0	.0	.0	.0	26.6
.13916	.0	.0	.0	.0	.0	.0	.0	.0	.0	31.1
.14451	.0	.0	.0	.0	.0	.0	.0	.0	.0	35.6
.14986	.0	.0	.0	.0	.0	.0	.0	.0	.0	40.1
.15521	.0	.0	.0	.0	.0	.0	.0	.0	.0	44.6
.16056	.0	.0	.0	.0	.0	.0	.0	.0	.0	49.0
.16591	.0	.0	.0	.0	.0	.0	.0	.0	.0	53.2
.17126	.0	.0	.0	.0	.0	.0	.0	.0	.0	57.1
.17661	.0	.0	.0	.0	.0	.0	.0	.0	.0	60.8
.18196	.0	.0	.0	.0	.0	.0	.0	.0	.0	64.2
.18731	.0	.0	.0	.0	.0	.0	.0	.0	.0	67.1
.19266	.0	.0	.0	.0	.0	.0	.0	.0	.0	69.6
.19801	.0	.0	.0	.0	.0	.0	.0	.0	.0	71.7
.20336	.0	.0	.0	.0	.0	.0	.0	.0	.0	73.2
.20871	.0	.0	.0	.0	.0	.0	.0	.0	.0	74.2
.21406	.0	.0	.0	.0	.0	.0	.0	.0	.0	74.7
.21941	.0	.0	.0	.0	.0	.0	.0	.0	.0	.1
.22476	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
.23011	.0	.0	.0	.0	.0	.0	.0	.0	.0	1.3
.23546	.0	.0	.0	.0	.0	.0	.0	.0	.0	3.4

THE PRINTED OUTPUT CONTAINING THE SOIL BEARING PRESSURE TIME HISTORIES FROM "t" = 0.23546 SECOND TO "t" = 1.20379 SECONDS HAS BEEN OMITTED.

EXAMPLE PROBLEM D.1 CANTILEVER WALL BARRIER ON COMPACT GRAVEL

BEARING PRESSURES IN SOIL AT SOIL ELEMENT ATTACHMENT POINTS FROM LEFT TO RIGHT END OF FOUNDATION(PSI)

ELEMENT NO. / TIME	1	2	3	4	5	6	7	8	9	10
1.20379	.0	.0	.0	.0	.0	.0	.0	.0	130.3	.0
1.20914	.0	.0	.0	.0	.0	.0	.0	.0	132.2	.0
1.21449	.0	.0	.0	.0	.0	.0	.0	.0	133.8	.0
1.21984	.0	.0	.0	.0	.0	.0	.0	.0	135.4	.0
1.22518	.0	.0	.0	.0	.0	.0	.0	.0	136.8	.0
1.23053	.0	.0	.0	.0	.0	.0	.0	.0	138.1	.0
1.23588	.0	.0	.0	.0	.0	.0	.0	.0	139.2	.0
1.24123	.0	.0	.0	.0	.0	.0	.0	3.9	140.1	.0
1.24658	.0	.0	.0	.0	.0	.0	.0	7.4	140.9	.0
1.25193	.0	.0	.0	.0	.0	.0	.0	11.3	141.6	.0
1.25728	.0	.0	.0	.0	.0	.0	.0	15.0	142.0	.0
1.26263	.0	.0	.0	.0	.0	.0	.0	18.5	142.3	.0
1.26798	.0	.0	.0	.0	.0	.0	.0	21.9	.0	.0
1.27333	.0	.0	.0	.0	.0	.0	.0	[illegible]	.3	.0
1.27868	.0	.0	.0	.0	.0	.0	.0	29.6	1.1	.0
1.28403	.0	.0	.0	.0	.0	.0	.0	34.1	2.4	.0
1.28938	.0	.0	.0	.0	.0	.0	.0	39.0	4.0	.0
1.29473	.0	.0	.0	.0	.0	.0	.0	44.3	6.0	.0
1.30008	.0	.0	.0	.0	.0	.0	.0	49.9	8.3	.0
1.30543	.0	.0	.0	.0	.0	.0	.0	55.0	11.0	.0
1.31078	.0	.0	.0	.0	.0	.0	.0	62.0	13.0	.0
1.31613	.0	.0	.0	.0	.0	.0	.0	68.4	16.9	.0
1.32148	.0	.0	.0	.0	.0	.0	.0	74.9	20.0	.0
1.32683	.0	.0	.0	.0	.0	.0	.0	81.9	23.2	.0
1.33218	.0	.0	.0	.0	.0	.0	.0	88.1	26.9	.0

MINIMUM VERTICAL DISPLACEMENT OF TOE BELOW THE GROUND .26 AT TIME .0000

MAX DISP OF C.G. IN X DIR (IN)= 37.84
MAX DISP OF C.G. IN Y DIR (IN)= 3.70
MAX ROTATION OF STR (DEGREE) = 20.09
MAX UPLIFT OF STR (IN)= -23.46

OVERTURNING ANGLE(DEGREES).....= 51.61
RATIO OF MAX ROTATION OF STR
TO OVERTURNING ANGLE...........= .39

MAX SOIL PRESSURE AT THE TOE(PSI) = 660.13

FOR DESIGN LOADS

MAX SHEAR AT .15L FROM FACE OF WALL(LB/IN) = -31832.5
CORRESPONDING MOMENT AT .15L (IN-LB/IN) = 1114838.2
MAX MOMENT AT FACE OF WALL(IN-LB/IN) = 1689732.2

CARD TYPE 1

Problem Identification (Title Card)
2 EXAMPLE PROBLEM D.2 SINGLE CELL BARRIER WITH BUTTRESS WALLS 71

CARD TYPE 2

1 5	6 10	11 15	16 20		26 30	31 35	36 40	41 45	46 50	51 55	56 60	61 65
NP	N	NS	NUMTM		ICI	ICAI	NDEL2	NUMPT	NWALL	NVEL	NFDN	NLOAD
6	1	15	2000		1	1	1	10	0	0	0	4

Figure D.5 Input data sheet - Example D.2: Card Types 1 and 2.

CARD TYPE 3

1 10	11 20	21 30	31 40	41 50	51 60	61 70
SOIL MODULUS E1	SOIL MODULUS E2	STRESS AT WHICH MODULUS CHANGES	COEFFICIENT OF FRICTION	POISSON'S RATIO	β_x	β_z
(PSI)	(PSI)	(PSI)				
5600.0	5600.0	1000.0	.70	.33	1.0	2.1

CARD TYPE 4

1 10	11 20	21 30	31 40	41 50	51 60	61 70
BACKWALL THICKNESS (TW)	C9	LENGTH OF BACKWALL (CL)	HEIGHT OF BACKWALL (FT)	SSB	HB	WIDTH OF HAUNCH (HAUNH)
(IN)		FT	FT			IN
34.0	.705	44.5	37.5	.539	.975	0.0

Figure D.6 Input data sheet - Example D.2: Card Types 3 and 4.

CARD TYPE 6

1 10	11 20
TASM	TOLG
(SEC)	(SEC)
.00036	.00742

CARD TYPE 8

1 10	11 20	21 30	31 40	41 50
WGT	I	XB	YB	XR
LBS	LBS-SEC^2/IN	IN	IN	IN
2957000.	510000000.	45.0	245.0	-203.0

Figure D.7 Input data sheet - Example D.2: Card Types 6 and 8.

CARD TYPE 9

1 — 10	11 — 20	21 — 30	31 — 40
A1	A2	A3	A4
IN^2	IN^2	IN^2	IN^2
135600.0	74412.0	62081.0	115188.0

Figure D.8 Input data sheet - Example D.2: Card Type 9.

① CARD TYPE 10: BACKWALL

1 10	11 20
X CORD (1)	Y CORD (1)
IN	IN
45.0	20.0

② CARD TYPE 10: FLOOR

1 10	11 20
X CORD (2)	Y CORD (2)
IN	IN
-79.0	245.0

③ CARD TYPE 10: ROOF

1 10	11 20
X CORD (3)	Y CORD (3)
IN	IN
-79.0	-205.0

④ CARD TYPE 10: FRONT WALL

1 10	11 20
X CORD (4)	Y CORD (4)
IN	IN
-202.9	-349.0

Figure D.9 Input data sheet - Example D.2: Card Type 10.

① CARD TYPE 11: BACKWALL

1 10	11 20
UVECT (1)	UVECT (2)
1.0	0.0

② CARD TYPE 11: FLOOR

1 10	11 20
UVECT (1)	UVECT (2)
0.0	1.0

③ CARD TYPE 11: ROOF

1 10	11 20
UVECT (1)	UVECT (2)
0.0	-1.0

④ CARD TYPE 11: FRONT WALL

1 10	11 20
UVECT (1)	UVECT (2)
1.0	0.0

Figure D.10 Input data sheet - Example D.2: Card Type 11.

1 CARD TYPE 12 : Charge No. 1 Backwall

1 10	11 20	21 30	31 40
IMPULSE ON SURFACE	T1	T2	P2/P1
PSI-MS	SEC	SEC	
460.6	.00048	.02096	

2 CARD TYPE 12 : Charge No. 1 Floor

1 10	11 20	21 30	31 40
IMPULSE ON SURFACE	T1	T2	P2/P1
PSI-MS	SEC	SEC	
448.9	.00246	.01733	

Figure D.11 Input data sheet - Example D.2: Charge Number 1, Card Type 12 for backwall and floor.

(3) CARD TYPE 12: Charge No. 1 Roof

1 10	11 20	21 30	31 40
IMPULSE ON SURFACE	T1	T2	P2/P1
PSI-MS	SEC	SEC	
336.1	.00866	.02499	

(4) CARD TYPE 12: Charge No. 1 Front Wall

1 10	11 20	21 30	31 40
IMPULSE ON SURFACE	T1	T2	P2/P1
PSI-MS	SEC	SEC	
48.42	.00507	.01641	

Figure D.12 Input data sheet - Example D.2: Charge Number 1, Card Type 12 for roof and front wall.

(1) CARD TYPE 12: Charge No. 2 Backwall

1 10	11 20	21 30	31 40	
IMPULSE ON SURFACE	T1	T2	P2/P1	
PSI-MS	SEC	SEC		
459.4	.00048	.01733		

(2) CARD TYPE 12: Charge No. 2 Floor

1 10	11 20	21 30	31 40	
IMPULSE ON SURFACE	T1	T2	P2/P1	
PSI-MS	SEC	SEC		
408.2	.00484	.02006		

Figure D.13 Input data sheet - Example D.2: Charge Number 2, Card Type 12 for backwall and floor.

(3) CARD TYPE 12: Charge No. 2 Roof

1 10	11 20	21 30	31 40
IMPULSE ON SURFACE	T1	T2	P2/P1
PSI-MS	SEC	SEC	
408.2	.00564	.02096	

(4) CARD TYPE 12: Charge No. 2 Front Wall

1 10	11 20	21 30	31 40
IMPULSE ON SURFACE	T1	T2	P2/P1
PSI-MS	SEC	SEC	
48.42	.00507	.01641	

Figure D.14 Input data sheet - Example D.2: Charge Number 2, Card Type 12 for roof and front wall.

(1) CARD TYPE 12: Charge No. 3 Backwall

1 10	11 20	21 30	31 40
IMPULSE ON SURFACE	T1	T2	P2/P1
PSI-MS	SEC	SEC	
912.2	.00036	.02016	

(2) CARD TYPE 12: Charge No. 3 Floor

1 10	11 20	21 30	31 40
IMPULSE ON SURFACE	T1	T2	P2/P1
PSI-MS	SEC	SEC	
916.2	.00168	.01540	

Figure D.15 Input data sheet - Example D.2: Charge Number 3, Card Type 12 for backwall and floor.

(3) CARD TYPE 12 : Charge No. 3 Roof

1 10	11 20	21 30	31 40	
IMPULSE ON SURFACE	T1	T2	P2/P1	
PSI-MS	SEC	SEC		
670.9	.00672	.02352		

(4) CARD TYPE 12 : Charge No. 3 Front Wall

1 10	11 20	21 30	31 40	
IMPULSE ON SURFACE	T1	T2	P2/P1	
PSI-MS	SEC	SEC		
75.59	.00388	.01323		

Figure D.16 Input data sheet - Example D.2: Charge Number 3, Card Type 12 for roof and front wall.

1 CARD TYPE 12 : Charge No. 4 Backwall

1 10	11 20	21 30	31 40
IMPULSE ON SURFACE	T1	T2	P2/P1
PSI-MS	SEC	SEC	
907.8	.00036	.01498	

2 CARD TYPE 12 : Charge No. 4 Floor

1 10	11 20	21 30	31 40
IMPULSE ON SURFACE	T1	T2	P2/P1
PSI-MS	SEC	SEC	
766.1	.00420	.01890	

Figure D.17 Input data sheet - Example D.2: Charge Number 4, Card Type 12 for backwall and floor.

③ CARD TYPE 12 : Charge No. 4 Roof

1 10	11 20	21 30	31 40
IMPULSE ON SURFACE	T1	T2	P2/P1
PSI-MS	SEC	SEC	
763.8	.00364	.01764	

④ CARD TYPE 12 : Charge No. 4 Front Wall

1 10	11 20	21 30	31 40
IMPULSE ON SURFACE	T1	T2	P2/P1
PSI-MS	SEC	SEC	
75.59	.00388	.01323	

Figure D.18 Input data sheet - Example D.2: Charge Number 4, Card Type 12 for roof and front wall.

(1) CARD TYPE 12: Charge No. 5 Backwall

1 10	11 20	21 30	31 40
IMPULSE ON SURFACE	T1	T2	P2/P1
PSI-MS	SEC	SEC	
906.6	.00140	.02254	

(2) CARD TYPE 12: Charge No. 5 Floor

1 10	11 20	21 30	31 40
IMPULSE ON SURFACE	T1	T2	P2/P1
PSI-MS	SEC	SEC	
873.0	.00179	.01470	

Figure D.19 Input data sheet - Example D.2: Charge Number 5, Card Type 12 for backwall and floor.

(3) CARD TYPE 12: Charge No. 5 Roof

1 10	11 20	21 30	31 40
IMPULSE ON SURFACE	T1	T2	P2/P1
PSI-MS	SEC	SEC	
658.6	.00700	.02352	

(4) CARD TYPE 12: Charge No. 5 Front Wall

1 10	11 20	21 30	31 40
IMPULSE ON SURFACE	T1	T2	P2/P1
PSI-MS	SEC	SEC	
71.57	.00381	.01123	

Figure D.20 Input data sheet - Example D.2: Charge Number 5, Card Type 12 for roof and front wall.

(1) CARD TYPE 12: Charge No. 6 Backwall

1 10	11 20	21 30	31 40
IMPULSE ON SURFACE	T1	T2	P2/P1
PSI-MS	SEC	SEC	
908.9	.00140	.01888	

(2) CARD TYPE 12: Charge No. 6 Floor

1 10	11 20	21 30	31 40
IMPULSE ON SURFACE	T1	T2	P2/P1
PSI-MS	SEC	SEC	
744.2	.00336	.01792	

Figure D.21 Input data sheet - Example D.2: Charge Number 6, Card Type 12 for backwall and floor.

③ CARD TYPE 12 : Charge No. 6 Roof

1 10	11 20	21 30	31 40
IMPULSE ON SURFACE	T1	T2	P2/P1
PSI-MS	SEC	SEC	
742.0	.00420	.01960	

④ CARD TYPE 12 : Charge No. 6 Front Wall

1 10	11 20	21 30	31 40
IMPULSE ON SURFACE	T1	T2	P2/P1
PSI-MS	SEC	SEC	
71.57	.00381	.01123	

Figure D.22 Input data sheet - Example D.2: Charge Number 6, Card Type 12 for roof and front wall.

EXAMPLE PROBLEM D.2 SINGLE CELL BARRIER WITH BUTTRESS WALLS

NUMBER OF CHARGES	6
NUMBER OF WALLS	1
NUMBER OF SOIL SPRINGS	15
NUMBER OF TIME INCREMENTS	2000
LEAST TIME OF ARRIVAL OF BLAST TO NEAREST POINT(SEC)	.00036
LEAST DURATION TIME(SEC)	.00742
PRINT FREQUENCY	10
INTEGRATION TIME INTERVAL 1(SEC)	3.71000E-04
INTEGRATION TIME INTERVAL 2(SEC)	3.71000E-04

SOIL PROPERTIES

MODULUS OF ELASTICITY E1(PSI)	5600.00
MODULUS OF ELASTICITY E2(PSI)	5600.00
NORMAL STRESS AT WHICH MODULUS CHANGES(PSI)	1000.00
COEFFICIENT OF FRICTION	.70
POISSONS RATIO	.33
SHAPE FACTOR BX	1.00
SHAPE FACTOR BY	2.10
KH1/SPRING(LB/IN)	105340.93
KV1/SPRING(LB/IN)	210390.73
KH2/SPRING(LB/IN)	105340.93
KV2/SPRING(LB/IN)	210390.73
KH1 TOTAL(LB/IN)	2700114.00
KV1 TOTAL(LB/IN)	3275060.96
KH2 TOTAL(LB/IN)	2700114.00
KV2 TOTAL(LB/IN)	3275060.96

STRUCTURE GEOMETRY

BACKWALL THICKNESS(IN)	36.000
RATIO OF SLAB THICKNESS TO BACKWALL THICKNESS	.785
LENGTH OF BACKWALL(FT)	44.500
HEIGHT OF BACKWALL(FT)	37.500
RATIO OF WIDTH OF FLOOR TO TOTAL WIDTH OF BASE	.539
RATIO OF HEIGHT OF WALL TO BASE OF STRUCTURE	.975
WIDTH OF BASE(IN)	461.53846
WIDTH OF LOADED AREA ON BASE(IN)	248.769
SLAB THICKNESS(IN)	23.973
RATIO OF WALL THICKNESS TO WIDTH OF STRUCTURE	.076
HORIZONTAL DISTANCE FROM CG TO REAR FACE OF WALL(IN)	45.080
VERTICAL DISTANCE FROM TOP OF FLOOR SLAB TO CG(IN)	245.980
DISTANCE FROM CG TO REAR END OF SLAB(IN)	-202.930
MASS(LB-SEC**2/IN)	7660.6
MASS MOMENT OF INERTIA(LB-IN-SEC**2)	9.10598E+08
WEIGHT(LBS)	2.99700E+06

EXAMPLE PROBLEM D.2 SINGLE CELL BARRIER WITH BUTTRESS WALLS

LOADING

CHARGE NUMBER 1

AREA OF FACE(IN**2) 135600.0
HORIZONTAL DISTANCE FROM CENTROID OF AREA TO CG(IN) 45.0
VERTICAL DISTANCE FROM CENTROID OF AREA TO CG(IN) 20.0

PRESSURE TIME CURVE

POINT 1 PRESSURE(PSI) 45.0 TIME(SEC) .00040
POINT 2 PRESSURE(PSI) .0 TIME(SEC) .02096

	TIME (SEC)	FORCE X (LBS)	FORCE Y (LBS)	MOMENT ABOUT Z (IN-LBS)
2	.00073	6.0246E+06	.0	-1.2049E+08
3	.00110	5.9141E+06	.0	-1.1828E+08
4	.00147	5.8036E+06	.0	-1.1607E+08
5	.00184	5.6931E+06	.0	-1.1386E+08
6	.00221	5.5826E+06	.0	-1.1165E+08
7	.00259	5.4721E+06	.0	-1.0944E+08
8	.00296	5.3617E+06	.0	-1.0723E+08
9	.00333	5.2512E+06	.0	-1.0502E+08
10	.00370	5.1407E+06	.0	-1.0281E+08
11	.00407	5.0302E+06	.0	-1.0060E+08
12	.00444	4.9197E+06	.0	-9.8394E+07
13	.00481	4.8092E+06	.0	-9.6184E+07
14	.00518	4.6987E+06	.0	-9.3974E+07
15	.00555	4.5882E+06	.0	-9.1764E+07
16	.00592	4.4777E+06	.0	-8.9554E+07
17	.00630	4.3672E+06	.0	-8.7345E+07
18	.00667	4.2567E+06	.0	-8.5135E+07
19	.00704	4.1462E+06	.0	-8.2925E+07
20	.00741	4.0358E+06	.0	-8.0715E+07
21	.00778	3.9253E+06	.0	-7.8505E+07
22	.00815	3.8148E+06	.0	-7.6296E+07
23	.00852	3.7043E+06	.0	-7.4086E+07
24	.00889	3.5938E+06	.0	-7.1876E+07
25	.00926	3.4833E+06	.0	-6.9666E+07
26	.00963	3.3728E+06	.0	-6.7456E+07
27	.01001	3.2623E+06	.0	-6.5246E+07
28	.01038	3.1518E+06	.0	-6.3037E+07
29	.01075	3.0413E+06	.0	-6.0827E+07
30	.01112	2.9308E+06	.0	-5.8617E+07
31	.01149	2.8204E+06	.0	-5.6407E+07
32	.01186	2.7099E+06	.0	-5.4197E+07
33	.01223	2.5994E+06	.0	-5.1987E+07
34	.01260	2.4889E+06	.0	-4.9778E+07
35	.01297	2.3784E+06	.0	-4.7568E+07
36	.01334	2.2679E+06	.0	-4.5358E+07
37	.01372	2.1574E+06	.0	-4.3148E+07
38	.01409	2.0469E+06	.0	-4.0938E+07
39	.01446	1.9364E+06	.0	-3.8728E+07
40	.01483	1.8259E+06	.0	-3.6519E+07
41	.01520	1.7154E+06	.	-3.4309E+07

42	.01557	[illegible]	.0	[illegible]
43	.01594	1.4945E+06	.0	-2.9889E+07
44	.01631	1.3840E+06	.0	-2.7679E+07
45	.01668	1.2735E+06	.0	-2.5470E+07
46	.01705	1.1630E+06	.0	-2.3260E+07
47	.01743	1.0525E+06	.0	-2.1050E+07
48	.01780	9.4200E+05	.0	-1.8840E+07
49	.01817	8.3151E+05	.0	-1.6630E+07
50	.01854	7.2102E+05	.0	-1.4420E+07
51	.01891	6.1053E+05	.0	-1.2211E+07
52	.01928	5.0004E+05	.0	-1.0001E+07
53	.01965	3.8955E+05	.0	-7.7910E+06
54	.02002	2.7906E+05	.0	-5.5811E+06
55	.02039	1.6857E+05	.0	-3.3713E+06
56	.02076	5.8075E+04	.0	-1.1615E+06

AREA OF FACE(IN**2) 74412.0
HORIZONTAL DISTANCE FROM CENTROID OF AREA TO CG(IN) -79.0
VERTICAL DISTANCE FROM CENTROID OF AREA TO CG(IN) 245.9

PRESSURE TIME CURVE

POINT 1 PRESSURE(PSI) 68.4 TIME(SEC) .00246
POINT 2 PRESSURE(PSI) .0 TIME(SEC) .01733

	TIME (SEC)	FORCE X (LBS)	FORCE Y (LBS)	MOMENT ABOUT Z (IN-LBS)
7	.00259	.0	4.4547E+06	-3.5192E+08
8	.00296	.0	4.3426E+06	-3.4306E+08
9	.00333	.0	4.2305E+06	-3.3421E+08
10	.00370	.0	4.1184E+06	-3.2535E+08
11	.00407	.0	4.0063E+06	-3.1650E+08
12	.00444	.0	3.8942E+06	-3.0764E+08
13	.00481	.0	3.7821E+06	-2.9879E+08
14	.00518	.0	3.6700E+06	-2.8993E+08
15	.00555	.0	3.5579E+06	-2.8108E+08
16	.00592	.0	3.4458E+06	-2.7222E+08
17	.00629	.0	3.3338E+06	-2.6337E+08
18	.00667	.0	3.2217E+06	-2.5451E+08
19	.00704	.0	3.1096E+06	-2.4566E+08
20	.00741	.0	2.9975E+06	-2.3680E+08
21	.00778	.0	2.8854E+06	-2.2795E+08
22	.00815	.0	2.7733E+06	-2.1909E+08
23	.00852	.0	2.6612E+06	-2.1024E+08
24	.00889	.0	2.5491E+06	-2.0138E+08
25	.00926	.0	2.4370E+06	-1.9252E+08
26	.00963	.0	2.3249E+06	-1.8367E+08
27	.01001	.0	2.2128E+06	-1.7481E+08
28	.01038	.0	2.1007E+06	-1.6596E+08
29	.01075	.0	1.9887E+06	-1.5710E+08
30	.01112	.0	1.8766E+06	-1.4825E+08
31	.01149	.0	1.7645E+06	-1.3939E+08
32	.01186	.0	1.6524E+06	-1.3054E+08
33	.01223	.0	1.5403E+06	-1.2168E+08
34	.01260	.0	1.4282E+06	-1.1283E+08
35	.01297	.0	1.3161E+06	-1.0397E+08
36	.01334	.0	1.2040E+06	-9.5117E+07
37	.01372	.0	1.0919E+06	-8.6261E+07
38	.01409	.0	9.7982E+05	-7.7406E+07
39	.01446	.0	8.6773E+05	-6.8551E+07
40	.01483	.0	7.5564E+05	-5.9695E+07
41	.01520	.0	6.4355E+05	-5.0840E+07
42	.01557	.0	5.3146E+05	-4.1985E+07
43	.01594	.0	4.1936E+05	-3.3130E+07

44	.01631	.0	3.0727E+05	-2.4274E+07
45	.01668	.0	1.9510E+05	-1.5419E+07
46	.01705	.0	8.3087E+04	-6.5639E+06

AREA OF FACE(IN**2) 62081.0
HORIZONTAL DISTANCE FROM CENTROID OF AREA TO CG(IN) -79.0
VERTICAL DISTANCE FROM CENTROID OF AREA TO CG(IN) -205.0

PRESSURE TIME CURVE

POINT 1 PRESSURE(PSI) 41.2 TIME(SEC) .00866
POINT 2 PRESSURE(PSI) .0 TIME(SEC) .02499

	TIME (SEC)	FORCE X (LBS)	FORCE Y (LBS)	MOMENT ABOUT Z (IN-LBS)
24	.00889	.0	-2.5190E+06	1.9988E+08
25	.00926	.0	-2.4610E+06	1.9442E+08
26	.00963	.0	-2.4029E+06	1.8983E+08
27	.01001	.0	-2.3448E+06	1.8524E+08
28	.01038	.0	-2.2868E+06	1.8066E+08
29	.01075	.0	-2.2287E+06	1.7607E+08
30	.01112	.0	-2.1707E+06	1.7148E+08
31	.01149	.0	-2.1126E+06	1.6690E+08
32	.01186	.0	-2.0545E+06	1.6231E+08
33	.01223	.0	-1.9965E+06	1.5772E+08
34	.01260	.0	-1.9384E+06	1.5314E+08
35	.01297	.0	-1.8804E+06	1.4855E+08
36	.01334	.0	-1.8223E+06	1.4396E+08
37	.01372	.0	-1.7643E+06	1.3938E+08
38	.01409	.0	-1.7062E+06	1.3479E+08
39	.01446	.0	-1.6481E+06	1.3020E+08
40	.01483	.0	-1.5901E+06	1.2562E+08
41	.01520	.0	-1.5320E+06	1.2103E+08
42	.01557	.0	-1.4740E+06	1.1644E+08
43	.01594	.0	-1.4159E+06	1.1186E+08
44	.01631	.0	-1.3579E+06	1.0727E+08
45	.01668	.0	-1.2998E+06	1.0268E+08
46	.01705	.0	-1.2417E+06	9.8098E+07
47	.01743	.0	-1.1837E+06	9.3511E+07
48	.01780	.0	-1.1256E+06	8.8925E+07
49	.01817	.0	-1.0676E+06	8.4338E+07
50	.01854	.0	-1.0095E+06	7.9752E+07
51	.01891	.0	-9.5146E+05	7.5165E+07
52	.01928	.0	-8.9340E+05	7.0578E+07
53	.01965	.0	-8.3534E+05	6.5992E+07
54	.02002	.0	-7.7728E+05	6.1405E+07
55	.02039	.0	-7.1923E+05	5.6819E+07
56	.02076	.0	-6.6117E+05	5.2232E+07
57	.02114	.0	-6.0311E+05	4.7646E+07
58	.02151	.0	-5.4505E+05	4.3059E+07
59	.02188	.0	-4.8699E+05	3.8473E+07
60	.02225	.0	-4.2893E+05	3.3886E+07
61	.02262	.0	-3.7088E+05	2.9300E+07
62	.02299	.0	-3.1282E+05	2.4713E+07
63	.02336	.0	-2.5476E+05	2.0126E+07
64	.02373	.0	-1.9670E+05	1.5540E+07
65	.02410	.0	-1.3865E+05	1.0953E+07
66	.02447	.0	-8.0592E+04	6.3668E+06
67	.02485	.0	-2.2534E+04	1.7802E+06

AREA OF FACE(IN**2) 115100.0
HORIZONTAL DISTANCE FROM CENTROID OF AREA TO CG(IN) -287.9
VERTICAL DISTANCE FROM CENTROID OF AREA TO CG(IN) -349.0

PRESSURE TIME CURVE

POINT 1 PRESSURE(PSI) 8.5 TIME(SEC) .00507
POINT 2 PRESSURE(PSI) .0 TIME(SEC) .01641

	TIME (SEC)	FORCE X (LBS)	FORCE Y (LBS)	MOMENT ABOUT Z (IN-LBS)
14	.00518	9.7387E+05	.0	3.3988E+08
15	.00555	9.4169E+05	.0	3.2865E+08
16	.00592	9.0950E+05	.0	3.1742E+08
17	.00630	8.7732E+05	.0	3.0619E+08
18	.00667	8.4514E+05	.0	2.9495E+08
19	.00704	8.1296E+05	.0	2.8372E+08
20	.00741	7.8078E+05	.0	2.7249E+08
21	.00778	7.4859E+05	.0	2.6126E+08
22	.00815	7.1641E+05	.0	2.5003E+08
23	.00852	6.8423E+05	.0	2.3880E+08
24	.00889	6.5205E+05	.0	2.2757E+08
25	.00926	6.1987E+05	.0	2.1633E+08
26	.00963	5.8769E+05	.0	2.0510E+08
27	.01001	5.5550E+05	.0	1.9387E+08
28	.01038	5.2332E+05	.0	1.8264E+08
29	.01075	4.9114E+05	.0	1.7141E+08
30	.01112	4.5896E+05	.0	1.6018E+08
31	.01149	4.2678E+05	.0	1.4895E+08
32	.01186	3.9460E+05	.0	1.3771E+08
33	.01223	3.6241E+05	.0	1.2648E+08
34	.01260	3.3023E+05	.0	1.1525E+08
35	.01297	2.9805E+05	.0	1.0402E+08
36	.01334	2.6587E+05	.0	9.2790E+07
37	.01372	2.3369E+05	.0	8.1557E+07
38	.01409	2.0150E+05	.0	7.0325E+07
39	.01446	1.6932E+05	.0	5.9094E+07
40	.01483	1.3714E+05	.0	4.7862E+07
41	.01520	1.0496E+05	.0	3.6631E+07
42	.01557	7.2778E+04	.0	2.5399E+07
43	.01594	4.0596E+04	.0	1.4168E+07
44	.01631	8.4141E+03	.0	2.9369E+06

THE PRINTED OUTPUT CONTAINING THE LOAD TIME HISTORIES FOR CHARGES 2 THROUGH 5 HAS BEEN OMITTED.

EXAMPLE PROBLEM D.2 SINGLE CELL BARRIER WITH BUTTRESS WALLS

LOADING

CHARGE NUMBER 6

AREA OF FACE(IN**2)	135600.0
HORIZONTAL DISTANCE FROM CENTROID OF AREA TO CG(IN)	45.0
VERTICAL DISTANCE FROM CENTROID OF AREA TO CG(IN)	20.0

PRESSURE TIME CURVE

POINT 1	PRESSURE(PSI)	104.0	TIME(SEC)	.00140
POINT 2	PRESSURE(PSI)	.0	TIME(SEC)	.01600

	TIME (SEC)	FORCE X (LBS)	FORCE Y (LBS)	MOMENT ABOUT Z (IN-LBS)
4	.00147	1.4043E+07	.0	-2.8085E+08
5	.00184	1.3743E+07	.0	-2.7487E+08
6	.00221	1.3444E+07	.0	-2.6888E+08
7	.00259	1.3145E+07	.0	-2.6289E+08
8	.00296	1.2845E+07	.0	-2.5691E+08
9	.00333	1.2546E+07	.0	-2.5092E+08
10	.00370	1.2247E+07	.0	-2.4494E+08
11	.00407	1.1948E+07	.0	-2.3895E+08
12	.00444	1.1648E+07	.0	-2.3296E+08
13	.00481	1.1349E+07	.0	-2.2698E+08
14	.00518	1.1050E+07	.0	-2.2099E+08
15	.00555	1.0750E+07	.0	-2.1501E+08
16	.00592	1.0451E+07	.0	-2.0902E+08
17	.00630	1.0152E+07	.0	-2.0304E+08
18	.00667	9.8525E+06	.0	-1.9705E+08
19	.00704	9.5532E+06	.0	-1.9106E+08
20	.00741	9.2539E+06	.0	-1.8508E+08
21	.00778	8.9546E+06	.0	-1.7909E+08
22	.00815	8.6553E+06	.0	-1.7311E+08
23	.00852	8.3560E+06	.0	-1.6712E+08
24	.00889	8.0567E+06	.0	-1.6113E+08
25	.00926	7.7574E+06	.0	-1.5515E+08
26	.00963	7.4581E+06	.0	-1.4916E+08
27	.01001	7.1588E+06	.0	-1.4318E+08
28	.01038	6.8595E+06	.0	-1.3719E+08
29	.01075	6.5602E+06	.0	-1.3120E+08
30	.01112	6.2610E+06	.0	-1.2522E+08
31	.01149	5.9617E+06	.0	-1.1923E+08
32	.01186	5.6624E+06	.0	-1.1325E+08
33	.01223	5.3631E+06	.0	-1.0726E+08
34	.01260	5.0638E+06	.0	-1.0128E+08
35	.01297	4.7645E+06	.0	-9.5290E+07
36	.01334	4.4652E+06	.0	-8.9304E+07
37	.01372	4.1659E+06	.0	-8.3318E+07
38	.01409	3.8666E+06	.0	-7.7332E+07
39	.01446	3.5673E+06	.0	-7.1346E+07
40	.01483	3.2680E+06	.0	-6.5360E+07
41	.01520	2.9687E+06	.0	-5.9374E+07
42	.01557	2.6694E+06	.0	-5.3388E+07
43	.01594	2.3701E+06	.0	-4.7402E+07

[illegible]	[illegible]	[illegible]	.0	[illegible]
45	.01668	1.7716E+06	.0	-3.5431E+07
46	.01705	1.4723E+06	.0	-2.9445E+07
47	.01743	1.1730E+06	.0	-2.3459E+07
48	.01780	8.7368E+05	.0	-1.7474E+07
49	.01817	5.7438E+05	.0	-1.1488E+07
50	.01854	2.7509E+05	.0	-5.5018E+06

AREA OF FACE(IN**2) 74412.0
HORIZONTAL DISTANCE FROM CENTROID OF AREA TO CG(IN) -79.0
VERTICAL DISTANCE FROM CENTROID OF AREA TO CG(IN) 245.9

PRESSURE TIME CURVE

POINT 1 PRESSURE(PSI) 102.2 TIME(SEC) .00336
POINT 2 PRESSURE(PSI) .0 TIME(SEC) .01792

	TIME (SEC)	FORCE X (LBS)	FORCE Y (LBS)	MOMENT ABOUT Z (IN-LBS)
10	.00370	.0	7.4297E+06	-5.8694E+08
11	.00407	.0	7.2359E+06	-5.7163E+08
12	.00444	.0	7.0420E+06	-5.5632E+08
13	.00481	.0	6.8482E+06	-5.4101E+08
14	.00518	.0	6.6544E+06	-5.2570E+08
15	.00555	.0	6.4605E+06	-5.1038E+08
16	.00592	.0	6.2667E+06	-4.9507E+08
17	.00630	.0	6.0729E+06	-4.7976E+08
18	.00667	.0	5.8791E+06	-4.6445E+08
19	.00704	.0	5.6852E+06	-4.4913E+08
20	.00741	.0	5.4914E+06	-4.3382E+08
21	.00778	.0	5.2976E+06	-4.1851E+08
22	.00815	.0	5.1038E+06	-4.0320E+08
23	.00852	.0	4.9099E+06	-3.8788E+08
24	.00889	.0	4.7161E+06	-3.7257E+08
25	.00926	.0	4.5223E+06	-3.5726E+08
26	.00963	.0	4.3284E+06	-3.4195E+08
27	.01001	.0	4.1346E+06	-3.2664E+08
28	.01038	.0	3.9408E+06	-3.1132E+08
29	.01075	.0	3.7470E+06	-2.9601E+08
30	.01112	.0	3.5531E+06	-2.8070E+08
31	.01149	.0	3.3593E+06	-2.6539E+08
32	.01186	.0	3.1655E+06	-2.5007E+08
33	.01223	.0	2.9717E+06	-2.3476E+08
34	.01260	.0	2.7778E+06	-2.1945E+08
35	.01297	.0	2.5840E+06	-2.0414E+08
36	.01334	.0	2.3902E+06	-1.8882E+08
37	.01371	.0	2.1964E+06	-1.7351E+08
38	.01408	.0	2.0025E+06	-1.5820E+08
39	.01446	.0	1.8087E+06	-1.4289E+08
40	.01483	.0	1.6149E+06	-1.2758E+08
41	.01520	.0	1.4210E+06	-1.1226E+08
42	.01557	.0	1.2272E+06	-9.6950E+07
43	.01594	.0	1.0334E+06	-8.1638E+07
44	.01631	.0	8.3957E+05	-6.6326E+07
45	.01668	.0	6.4574E+05	-5.1014E+07
46	.01705	.0	4.5191E+05	-3.5701E+07
47	.01743	.0	2.5808E+05	-2.0389E+07
48	.01780	.0	6.4241E+04	-5.0768E+06

AREA OF FACE(IN**2) 62881.2
HORIZONTAL DISTANCE FROM CENTROID OF AREA TO CG(IN) -79.0
VERTICAL DISTANCE FROM CENTROID OF AREA TO CG(IN) -204.8

PRESSURE TIME CURVE

POINT 1 PRESSURE(PSI) 96.4 TIME(SEC) .00420
POINT 2 PRESSURE(PSI) .0 TIME(SEC) .01960

	TIME (SEC)	FORCE X (LBS)	FORCE Y (LBS)	MOMENT ABOUT Z (IN-LBS)
12	.00444	.0	-5.8887E+06	4.6521E+08
13	.00481	.0	-5.7446E+06	4.5382E+08
14	.00518	.0	-5.6005E+06	4.4244E+08
15	.00555	.0	-5.4564E+06	4.3105E+08
16	.00592	.0	-5.3122E+06	4.1967E+08
17	.00630	.0	-5.1681E+06	4.0828E+08
18	.00667	.0	-5.0240E+06	3.9690E+08
19	.00704	.0	-4.8799E+06	3.8551E+08
20	.00741	.0	-4.7358E+06	3.7413E+08
21	.00778	.0	-4.5916E+06	3.6274E+08
22	.00815	.0	-4.4475E+06	3.5135E+08
23	.00852	.0	-4.3034E+06	3.3997E+08
24	.00889	.0	-4.1593E+06	3.2858E+08
25	.00926	.0	-4.0152E+06	3.1720E+08
26	.00963	.0	-3.8710E+06	3.0581E+08
27	.01001	.0	-3.7269E+06	2.9443E+08
28	.01038	.0	-3.5828E+06	2.[illegible]04E+08
29	.01075	.0	-3.4387E+06	2.[illegible]66E+08
30	.01112	.0	-3.2946E+06	2.6027E+08
31	.01149	.0	-3.1504E+06	2.4889E+08
32	.01186	.0	-3.0063E+06	2.3750E+08
33	.01223	.0	-2.8622E+06	2.2611E+08
34	.01260	.0	-2.7181E+06	2.1473E+08
35	.01297	.0	-2.5740E+06	2.0334E+08
36	.01334	.0	-2.4298E+06	1.9196E+08
37	.01372	.0	-2.2857E+06	1.8057E+08
38	.01409	.0	-2.1416E+06	1.6919E+08
39	.01446	.0	-1.9975E+06	1.5780E+08
40	.01483	.0	-1.8534E+06	1.4642E+08
41	.01520	.0	-1.7092E+06	1.3503E+08
42	.01557	.0	-1.5651E+06	1.2364E+08
43	.01594	.0	-1.4210E+06	1.1226E+08
44	.01631	.0	-1.2769E+06	1.0087E+08
45	.01668	.0	-1.1328E+06	8.9488E+07
46	.01705	.0	-9.8864E+05	7.8103E+07
47	.01743	.0	-8.4452E+05	6.6717E+07
48	.01780	.0	-7.0040E+05	5.5332E+07
49	.01817	.0	-5.5628E+05	4.3946E+07
50	.01854	.0	-4.1216E+05	3.2561E+07
51	.01891	.0	-2.6804E+05	2.1175E+07
52	.01928	.0	-1.2392E+05	9.7897E+06

AREA OF FACE(IN**2) 115188.0
HORIZONTAL DISTANCE FROM CENTROID OF AREA TO CG(IN) -202.9
VERTICAL DISTANCE FROM CENTROID OF AREA TO CG(IN) -344.6

PRESSURE TIME CURVE

POINT 1 PRESSURE(PSI) 19.3 TIME(SEC) .00381
POINT 2 PRESSURE(PSI) .0 TIME(SEC) .01123

	TIME (SEC)	FORCE X (LBS)	FORCE Y (LBS)	MOMENT ABOUT Z (IN-LBS)
11	.00407	2.1447E+06	.0	7.6914E+08
12	.00444	2.0321E+06	.0	7.0555E+08
13	.00481	1.9228E+06	.0	6.7094E+08

14	.00518	[illegible]	.0	[illegible]
15	.00555	1.6990E+06	.0	5.9326E+08
16	.00592	1.5887E+06	.0	5.5446E+08
17	.00630	1.4776E+06	.0	5.1569E+08
18	.00667	1.3665E+06	.0	4.7691E+08
19	.00704	1.2554E+06	.0	4.3813E+08
20	.00741	1.1443E+06	.0	3.9936E+08
21	.00778	1.0332E+06	.0	3.6058E+08
22	.00815	9.2208E+05	.0	3.2180E+08
23	.00852	8.1098E+05	.0	2.8303E+08
24	.00889	6.9987E+05	.0	2.4426E+08
25	.00926	5.8877E+05	.0	2.0548E+08
26	.00963	4.7766E+05	.0	1.6670E+08
27	.01001	3.6656E+05	.0	1.2793E+08
28	.01038	2.5545E+05	.0	8.9153E+07
29	.01075	1.4435E+05	.0	5.0377E+07
30	.01112	3.3242E+04	.0	1.1601E+07

EXAMPLE PROBLEM C.2 SINGLE CELL BARRIER WITH BUTTRESS WALLS

LOADING

	TIME (SEC)	FORCE X (LBS)	FORCE Y (LBS)	MOMENT ABOUT Z (IN-LBS)
1	.00036	2.9334E+07	.0	-5.4660E+08
2	.00073	4.1981E+07	.0	-8.3962E+08
3	.00110	4.1046E+07	.0	-8.2093E+08
4	.00147	6.5745E+07	.0	-1.1149E+09
5	.00184	6.4306E+07	1.9041E+07	-2.0536E+09
6	.00221	6.2068E+07	1.9243E+07	-2.7807E+09
7	.00259	6.1438E+07	2.3180E+07	-3.0598E+09
8	.00296	5.9992E+07	2.2510E+07	-2.9701E+09
9	.00333	5.8554E+07	2.1840E+07	-2.8964E+09
10	.00370	5.7116E+07	2.1854E+07	-2.8688E+09
11	.00407	6.3615E+07	2.1170E+07	-1.5693E+07
12	.00444	6.1407E+07	2.?226E+07	-1.9947E+08
13	.00481	5.9999E+07	2.1490E+07	-2.4170E+08
14	.00518	6.0139E+07	2.4655E+07	8.7607E+07
15	.00555	5.0266E+07	2.3022E+07	3.0601E+07
16	.00592	5.6194E+07	1.9742E+07	2.3009E+08
17	.00630	5.4521E+07	1.0909E+07	1.6675E+08
18	.00667	5.2649E+07	1.0235E+07	1.0342E+08
19	.00704	5.0776E+07	8.6793E+06	8.1452E+08
20	.00741	4.8904E+07	7.1468E+06	7.3176E+08
21	.00778	4.7031E+07	6.5143E+06	6.5299E+08
22	.00815	4.5159E+07	6.2810E+06	5.7222E+08
23	.00852	4.3286E+07	5.5493E+06	4.9146E+08
24	.00889	4.1414E+07	2.6977E+06	4.2969E+08
25	.00926	3.9541E+07	2.0233E+06	5.2434E+08
26	.00963	3.7669E+07	1.5489E+06	4.3098E+08
27	.01001	3.5796E+07	1.0744E+06	3.5163E+08
28	.01038	1.3923E+07	5.9992E+59	2.6820E+28
29	.01075	3.2051E+07	1.2993E+55	1.0292E+08
30	.01112	3.0178E+07	-3.4091E+35	9.7500E+07
31	.01149	2.8462E+07	-8.2330E+05	8.6963E+07
32	.01186	2.6011E+07	-1.2970E+26	5.0761E+07
33	.01223	2.5161E+07	-1.2722E+06	5.0999E+07
34	.01260	2.3511E+07	-2.2467E+06	4.3196E+07
35	.01297	2.1868E+07	-2.7211E+06	3.5394E+07
36	.01334	2.2254E+07	-3.1990E+06	4.3641E+07
37	.01372	1.8712E+07	-3.6700E+06	8.7322E+07
38	.01409	1.7257E+07	-4.1445E+06	1.3110E+08
39	.01446	1.5744E+07	-4.6109E+06	1.7400E+08
40	.01483	1.4244E+07	-4.9920E+06	3.1072E+08
41	.01520	1.2997E+07	-5.1708E+06	2.2659E+08
42	.01557	1.1922E+07	-5.2344E+06	2.2919E+08
43	.01594	1.0407E+07	-5.1999E+06	2.2034E+08
44	.01631	9.7714E+06	-5.0724E+06	2.1190E+08
45	.01668	8.7430E+06	-4.9009E+06	[illegible]
46	.01705	7.7129E+06	-4.5854E+06	2.3287E+08
47	.01742	6.7641E+06	-4.7029E+06	2.4335E+08
48	.01780	5.9103E+06	-4.6730E+06	2.5040E+08
49	.01817	5.8602E+06	-4.5276E+06	2.5622E+08
50	.01854	4.2292E+06	-3.3177E+06	2.5669E+08
51	.01891	3.5996E+06	-3.1025E+06	2.9617E+08
52	.01928	2.8477E+06	-2.6995E+06	2.1521E+08
53	.01965	2.2951E+06	-2.3114E+06	2.1542E+08
54	.02002	1.7003E+06	-3.0444E+06	2.0993E+08

[illegible]	.02039	[illegible]	[illegible]	[illegible]
56	.02076	1.0356E+06	-2.3419E+06	1.6432E+08
57	.02114	7.7244E+05	-2.0210E+06	1.4421E+08
58	.02151	4.6032E+05	-1.7423E+06	1.2620E+08
59	.02188	3.4421E+05	-1.4436E+06	1.0934E+08
60	.02225	1.6918E+05	-1.1849E+06	9.0485E+07
61	.02262	.0	-9.0618E+05	7.1900E+07
62	.02299	.0	-6.2746E+05	4.9949E+07
63	.02336	.0	-3.4874E+05	2.7550E+07
64	.02373	.0	-1.9671E+05	1.5546E+07
65	.02411	.0	-1.3865E+05	1.0993E+07
66	.02447	.0	-8.1592E+04	6.3600E+06
67	.02484	.0	-2.2934E+04	1.7403E+06

FORCE VECTOR EQUALS ZERO AFTER TIME .02484

EXAMPLE PROBLEM D.2 SINGLE CELL BARRIER WITH BUTTRESS WALLS

TIME (SEC)	DISPLACEMENT OF C.G. X (IN)	Y (IN)	THETA (DEG)	RESISTING FORCES X (LBS)	Y (LBS)	THETA (IN-LBS)	XFDN (IN)
.00036	.0	.0	.0	.0	2.9570E+06	.0	.0
.00407	4.7317E-02	8.7787E-03	-1.2566E-03	1.3104E+05	2.0764E+06	-2.8184E+08	5.3236E-02
.00778	2.0063E-01	5.4946E-02	-4.0250E-03	5.9352E+05	2.2233E+06	-3.2574E+08	2.1959E-01
.01149	4.3774E-01	1.1876E-01	-5.6885E-03	1.2721E+06	2.6298E+06	-5.0491E+08	4.6366E-01
.01520	7.2329E-01	1.8218E-01	-6.1358E-03	1.8457E+06	2.8367E+06	-6.5455E+08	7.5219E-01
.01691	1.0306E+00	2.3813E-01	-5.3879E-03	1.9748E+06	2.8212E+06	-6.8339E+08	1.0560E+00
.02262	1.3417E+00	2.8752E-01	-3.2441E-03	2.0905E+06	2.9864E+06	-7.0754E+08	1.3570E+00
.02633	1.6497E+00	3.3489E-01	1.1525E-04	2.2028E+06	3.1469E+06	-7.2955E+08	1.6492E+00
.03004	1.9538E+00	3.8187E-01	4.6063E-03	2.3156E+06	3.3080E+06	-7.5035E+08	1.9321E+00
.03375	2.2536E+00	4.2822E-01	1.0257E-02	2.4282E+06	3.4688E+06	-7.6980E+08	2.2053E+00
.03746	2.5492E+00	4.7365E-01	1.7099E-02	2.5400E+06	3.6285E+06	-7.8772E+08	2.4606E+00
.04117	2.8401E+00	5.1787E-01	2.5158E-02	2.6504E+06	3.7862E+06	-8.0393E+08	2.7216E+00
.04488	3.1263E+00	5.6061E-01	3.4460E-02	2.7587E+06	3.9411E+06	-8.1828E+08	2.9648E+00
.04859	3.4075E+00	6.0157E-01	4.5027E-02	2.8645E+06	4.0921E+06	-8.3059E+08	3.1954E+00
.05230	3.6838E+00	6.4060E-01	5.6779E-02	2.7123E+06	3.8747E+06	-6.9884E+08	3.4164E+00
.05601	3.9553E+00	6.7847E-01	6.9580E-02	2.5611E+06	3.6587E+06	-5.7754E+08	3.6276E+00
.05972	4.2222E+00	7.1481E-01	8.3294E-02	2.6623E+06	3.8033E+06	-5.8685E+08	3.8298E+00
.06343	4.4843E+00	7.4971E-01	9.7895E-02	2.5099E+06	3.5856E+06	-4.7605E+08	4.0232E+00
.06714	4.7418E+00	7.8337E-01	1.1326E-01	2.6097E+06	3.7281E+06	-4.8326E+08	4.2083E+00
.07085	4.9946E+00	8.1565E-01	1.2937E-01	2.7088E+06	3.8697E+06	-4.8996E+08	4.3853E+00
.07456	5.2426E+00	8.4635E-01	1.4623E-01	2.5515E+06	3.64[illegible]	-3.8904E+08	4.5539E+00
.07827	5.4860E+00	8.7572E-01	1.6371E-01	2.6490E+06	3.78[illegible]	-3.9463E+08	4.7149E+00
.08198	5.7246E+00	9.0361E-01	1.8180E-01	2.7457E+06	3.92[illegible]	-4.0027E+08	4.8683E+00
.08569	5.9583E+00	9.2975E-01	2.0051E-01	2.8412E+06	4.05[illegible]	-4.0531E+08	5.0139E+00
.08940	6.1869E+00	9.5397E-01	2.1983E-01	2.6715E+06	3.816[illegible]	-3.1169E+08	5.1514E+00
.09311	6.4106E+00	9.7649E-01	2.3967E-01	2.7643E+06	3.9490E+06	-3.1599E+08	5.2817E+00
.09682	6.6293E+00	9.9723E-01	2.6000E-01	2.8558E+06	4.0798E+06	-3.2001E+08	5.4047E+00
.10053	6.8479E+00	1.0160E+00	2.8083E-01	2.9457E+06	4.2082E+06	-3.2372E+08	5.5202E+00
.10424	7.0512E+00	1.0324E+00	3.0215E-01	3.0337E+06	4.3336E+06	-3.2709E+08	5.6288E+00
.10795	7.2542E+00	1.0466E+00	3.2395E-01	2.8401E+06	4.0573E+06	-2.3898E+08	5.7283E+00
.11166	7.4520E+00	1.0567E+00	3.4613E-01	2.9243E+06	4.1776E+06	-2.4177E+08	5.8217E+00
.11537	7.6446E+00	1.0697E+00	3.6868E-01	3.0066E+06	4.2952E+06	-2.4433E+08	5.9088E+00
.11908	7.8317E+00	1.0762E+00	3.9161E-01	3.0868E+06	4.4097E+06	-2.4664E+08	5.9872E+00
.12279	8.0134E+00	1.0811E+00	4.1492E-01	3.1646E+06	4.5208E+06	-2.4868E+08	6.0590E+00
.12650	8.1894E+00	1.0833E+00	4.3861E-01	2.9349E+06	4.1927E+06	-1.6513E+08	6.1235E+00
.13021	8.3600E+00	1.0832E+00	4.6256E-01	3.0080E+06	4.2971E+06	-1.6669E+08	6.1813E+00
.13392	8.5252E+00	1.0807E+00	4.8678E-01	3.0779E+06	4.3984E+06	-1.6810E+08	6.2325E+00
.13763	8.6849E+00	1.0755E+00	5.1126E-01	3.147[illegible]	[illegible]4964E+06	-1.6933E+08	6.2769E+00
.14134	8.8390E+00	1.0676E+00	5.3599E-01	3.2134[illegible]	4.5906E+06	-1.7037E+08	6.3144E+00
.14505	8.9873E+00	1.0568E+00	5.6099E-01	3.2765E+06	4.6809E+06	-1.7121E+08	6.3450E+00
.14876	9.1299E+00	1.0432E+00	5.8620E-01	2.9951E+06	4.2801E+06	-9.2262E+07	6.3685E+00
.15247	9.2672E+00	1.0273E+00	6.1156E-01	3.054[illegible]E+06	4.3638E+06	-9.2627E+07	6.3868E+00
.15618	9.3990E+00	1.0089E+00	6.3705E-01	3.1110E+06	4.4443E+06	-9.3100E+07	6.3985E+00
.15989	9.5252E+00	9.8777E-01	6.3269E-01	3.1549E+06	4.5213E+06	-9.3471E+07	6.4039E+00
.16360	9.6457E+00	9.6385E-01	6.8848E-01	3.1693E+06	4.5946E+06	-6.6308E+07	6.4030E+00
.16731	9.7605E+00	9.3701E-01	7.1439E-01	2.7917E+06	4.1058E+06	1.7103E+06	6.3958E+00
.17102	9.8701E+00	9.0783E-01	7.4333E-01	2.7777E+06	4.1731E+06	1.8118E+07	6.3832E+00
.17473	9.9748E+00	8.7646E-01	7.6625E-01	2.7583E+06	4.2364E+06	3.5451E+07	6.3658E+00

THE PRINTED OUTPUT CONTAINING THE REMAINDER OF THE DISPLACEMENT TIME HISTORIES HAS BEEN OMITTED.

EXAMPLE PROBLE' D.2 SINGLE CELL BARRIER WITH BUTTRESS WALLS

BEARING PRESSURES IN SOIL AT SOIL ELEMENT ATTACHMENT POINTS FROM LEFT TO RIGHT END OF FOUNDATION(PSI)

ELEMENT NO. TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
.00036	16.3	15.7	15.1	14.5	13.9	13.2	12.6	12.0	11.4	10.8	10.1	9.5	8.9	8.3	7.7
.00407	16.5	15.9	15.3	14.6	14.0	13.4	12.7	12.1	11.5	.1	.1	.1	.1	.1	.0
.00778	17.3	16.6	16.0	15.3	14.7	14.0	13.4	12.7	12.1	.6	.6	.6	.6	.5	.5
.01149	18.2	17.5	16.9	16.2	15.5	14.9	14.2	13.5	12.9	1.5	1.4	1.4	1.3	1.3	1.2
.01520	19.1	18.4	17.7	17.1	16.4	15.7	15.0	14.4	13.7	2.3	2.2	2.2	2.1	2.1	2.1
.01891	19.8	19.1	18.4	17.8	17.1	16.5	15.8	15.1	14.5	3.0	3.0	3.0	2.9	2.9	2.8
.02262	20.3	19.7	19.0	18.4	17.7	17.1	16.4	15.8	15.2	3.8	3.7	3.7	3.7	3.7	3.6
.02633	20.8	20.2	19.6	18.9	18.3	17.7	17.1	16.4	15.8	4.5	4.5	4.5	4.5	4.5	4.5
.03004	21.2	20.6	20.0	19.4	18.9	18.3	17.7	17.1	16.5	5.2	5.2	5.2	5.3	5.3	5.4
.03375	21.6	21.0	20.5	19.9	19.4	18.8	18.3	17.8	17.2	5.9	6.0	6.1	6.2	6.2	6.3
.03746	21.8	21.3	20.9	20.4	19.9	19.4	18.9	18.4	17.9	6.7	6.8	6.9	7.1	7.2	7.3
.04117	22.0	21.6	21.2	20.8	20.3	19.9	19.5	19.0	18.6	7.4	7.6	7.8	8.0	8.2	8.4
.04488	22.2	21.8	21.5	21.1	20.7	20.4	20.0	19.7	19.3	8.2	8.5	8.7	9.0	9.3	9.5
.04859	22.2	21.9	21.7	21.4	21.1	20.8	20.6	20.3	20.0	9.0	9.3	9.7	10.0	10.4	10.7
.05230	.0	22.0	21.8	21.6	21.4	21.3	21.1	20.9	20.7	9.8	10.2	10.6	11.1	11.5	11.9
.05601	.0	.0	21.9	21.8	21.7	21.6	21.6	21.5	21.4	10.5	11.1	11.6	12.1	12.7	13.2
.05972	.0	.0	22.0	22.0	22.0	22.0	22.0	22.0	22.1	11.3	12.0	12.6	13.2	13.9	14.5
.06343	.0	.0	.0	22.1	22.2	22.3	22.5	22.6	22.7	12.1	12.8	13.6	14.3	15.1	15.8
.06714	.0	.0	.0	22.2	22.4	22.7	22.9	23.1	23.4	12.9	13.7	14.6	15.5	16.3	17.2
.07085	.0	.0	.0	22.2	22.6	22.9	23.3	23.7	24.0	13.7	14.6	15.6	16.6	17.6	18.6
.07456	.0	.0	.0	.0	22.7	23.2	23.7	24.2	24.7	14.4	15.5	16.7	17.8	18.9	20.0
.07827	.0	.0	.0	.0	22.8	23.4	24.1	24.7	25.3	15.2	16.5	17.7	19.0	20.2	21.5
.08198	.0	.0	.0	.0	22.9	23.6	24.4	25.2	26.0	16.0	17.4	18.7	20.1	21.5	22.9
.08569	.0	.0	.0	.0	22.9	23.8	24.7	25.7	26.6	16.7	18.3	19.8	21.3	22.9	24.4
.08940	.0	.0	.0	.0	.0	24.0	25.0	26.1	27.2	17.5	19.1	20.8	22.5	24.2	25.9
.09311	.0	.0	.0	.0	.0	24.1	25.3	26.5	27.7	18.2	20.0	21.9	23.7	25.5	27.4
.09682	.0	.0	.0	.0	.0	24.2	25.6	26.9	28.3	18.9	20.9	22.9	24.9	26.9	28.9
.10053	.0	.0	.0	.0	.0	24.3	25.8	27.3	28.8	19.6	21.8	23.9	26.1	28.2	30.4
.10424	.0	.0	.0	.0	.0	24.3	26.0	27.7	29.4	20.3	22.6	24.9	27.2	29.5	31.9
.10795	.0	.0	.0	.0	.0	.0	26.1	28.0	29.9	21.0	23.4	25.9	28.4	30.9	33.3
.11166	.0	.0	.0	.0	.0	.0	26.3	28.3	30.3	21.6	24.3	26.9	29.5	32.2	34.8
.11537	.0	.0	.0	.0	.0	.0	26.4	28.6	30.8	22.2	25.0	27.9	30.7	33.5	36.3
.11908	.0	.0	.0	.0	.0	.0	26.5	28.8	31.2	22.8	25.8	28.8	31.8	34.8	37.8
.12279	.0	.0	.0	.0	.0	.0	26.5	29.1	31.6	23.4	26.6	29.7	32.9	36.1	39.3
.12650	.0	.0	.0	.0	.0	.0	.0	29.2	32.0	23.9	27.3	30.7	34.0	37.4	40.7
.13021	.0	.0	.0	.0	.0	.0	.0	29.4	32.3	24.5	28.0	31.5	35.1	38.6	42.2
.13392	.0	.0	.0	.0	.0	.0	.0	29.5	32.6	25.0	28.7	32.4	36.1	39.8	43.6
.13763	.0	.0	.0	.0	.0	.0	.0	29.6	32.9	25.4	29.3	33.2	37.2	41.1	45.0
.14134	.0	.0	.0	.0	.0	.0	.0	29.7	33.1	25.9	30.0	34.1	38.2	42.2	46.3
.14505	.0	.0	.0	.0	.0	.0	.0	29.7	33.3	26.3	30.5	34.8	39.1	43.4	47.7
.14876	.0	.0	.0	.0	.0	.0	.0	.0	33.5	26.6	31.1	35.6	40.1	44.6	49.0
.15247	.0	.0	.0	.0	.0	.0	.0	.0	33.7	27.0	31.6	36.3	41.0	45.7	50.3
.15618	.0	.0	.0	.0	.0	.0	.0	.0	33.8	27.3	32.1	37.0	41.9	46.8	51.6
.15989	.0	.0	.0	.0	.0	.0	.0	.0	33.9	27.5	32.6	37.7	42.8	47.8	52.9
.16360	.0	.0	.0	.0	.0	.0	.0	.0	33.9	27.8	33.1	38.3	43.6	48.9	54.1

THE PRINTED OUTPUT CONTAINING THE SOIL BEARING PRESSURE TIME HISTORIES FROM "t" = 0.16360 SECOND TO "t" = 0.66816 SECOND HAS BEEN OMITTED.

EXAMPLE PROBLEM D.2 SINGLE CELL BARRIER WITH BUTTRESS WALLS

BEARING PRESSURES IN SOIL AT SOIL ELEMENT ATTACHMENT POINTS FROM LEFT TO RIGHT END OF FOUNDATION(PSI)

ELEMENT NO. TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
.66816	10.5	15.5	20.3	24.9	28.9	32.3	34.9	36.5	37.1	.0	.0	.0	.0	.0	.0
.67187	11.5	16.3	21.1	25.5	29.4	32.7	35.2	36.7	37.2	.0	.0	.0	.0	.0	.0
.67558	12.4	17.2	21.8	26.1	29.9	33.1	35.5	36.9	37.2	.0	.0	.0	.0	.0	.0
.67929	13.3	18.0	22.5	26.7	30.4	33.5	35.7	37.0	.0	.0	.0	.0	.0	.0	.0
.68300	14.2	18.8	23.2	27.2	30.9	33.8	35.9	37.1	.0	.0	.0	.0	.0	.0	.0
.68671	15.1	19.6	23.8	27.8	31.3	34.1	36.1	37.2	.0	.0	.0	.0	.0	.0	.0
.69042	16.0	20.3	24.5	28.3	31.7	34.4	36.3	37.3	.0	.0	.0	.0	.0	.0	.0
.69413	16.9	21.1	25.1	28.8	32.1	34.7	36.5	37.3	.0	.0	.0	.0	.0	.0	.0
.69784	17.7	21.8	25.7	29.3	32.5	35.0	36.6	37.3	.0	.0	.0	.0	.0	.0	.0
.70155	18.5	22.5	26.3	29.8	32.8	35.2	36.8	.0	.0	.0	.0	.0	.0	.0	.0
.70526	19.3	23.1	26.8	30.2	33.2	35.4	36.9	.0	.0	.0	.0	.0	.0	.0	.0
.70897	20.1	23.8	27.4	30.7	33.5	35.6	37.0	.0	.0	.0	.0	.0	.0	.0	.0
.71268	20.8	24.5	27.9	31.1	33.8	35.8	37.1	.0	.0	.0	.0	.0	.0	.0	.0
.71639	21.6	25.1	28.5	31.5	34.1	36.0	37.1	.0	.0	.0	.0	.0	.0	.0	.0
.72010	22.3	25.7	29.0	31.9	34.4	36.2	37.2	.0	.0	.0	.0	.0	.0	.0	.0
.72381	23.1	26.4	29.5	32.3	34.7	36.4	37.2	.0	.0	.0	.0	.0	.0	.0	.0
.72752	23.8	26.9	30.0	32.7	34.9	36.5	37.3	.0	.0	.0	.0	.0	.0	.0	.0
.73123	24.5	27.5	30.4	33.0	35.2	36.6	37.3	.0	.0	.0	.0	.0	.0	.0	.0
.73494	25.1	28.1	30.9	33.4	35.4	36.8	.0	.0	.0	.0	.0	.0	.0	.0	.0
.73865	25.8	28.6	31.3	33.7	35.6	36.9	.0	.0	.0	.0	.0	.0	.0	.0	.0

MINIMUM VERTICAL DISPLACEMENT OF TOE BELOW THE GROUND .81 AT TIME .00147

```
MAX DISP OF C.G. IN X DIR (IN)=      11.90
MAX DISP OF C.G. IN Y DIR (IN)=       3.89
MAX ROTATION OF STR ( DEGREE) =       1.59
MAX UPLIFT   OF STR       (IN)=      -1.18

OVERTURNING ANGLE(DEGREES)....=      43.78
RATIO OF MAX ROTATION OF STR
TO OVERTURNING ANGLE..........=        .04


MAX SOIL PRESSURE AT THE TOE(PSI)     =         91.41


PROBLEM SOLUTION COMPLETED
```

APPENDIX E

LIST OF SYMBOLS USED IN TEXT

A	Surface area of foundation (ft^2)
A_b	Cross-sectional area of steel reinforcing bar (in^2)
A_{min}	Minimum area of flexural reinforcement (in^2/ft)
A_s	Area of tension reinforcement within a width "b" (in^2/ft)
a	Depth of equivalent rectangular stress block (in)
B	Width of foundation along axis of rotation for rocking or normal to direction of horizontal force (in)
b	Width of compression face of flexural member (in)
c	Thickness of bottom concrete cover (in)
c_I, c_{II}	Distance from resultant of applied loads to axis of rotation for Sectors I and II, respectively (in)
d	Distance from extreme compression fiber to centroid of tension reinforcement (in)
d_b	Diameter of tension reinforcement bar (in)
d_c	Distance between centroids of the compression and tension reinforcement (in)
f_c	Friction factor for cohesive soils
f'_c	Static ultimate compressive strength of concrete at 28 days (psi)
f_{ds}	Dynamic design stress for reinforcement (psi)
f_s	Static design stress for reinforcement (psi)
G	Shear modulus for soil (psi)
g	Acceleration of gravity (in/sec^2)

H	Distance, in vertical direction, between supports and/or free edges of foundation extension supported on three or four sides (in)
H(t)	Resultant of horizontal blast loads acting on structure at time "t" (lbs)
HW	Height of backwall (ft)
h	Charge location parameter (ft)
h'	Distance from center of gravity of structure to soil-structure interface (in)
I	Mass moment of inertia of structure (lb-sec^2/in)
$\bar{i}_b$	Scaled unit blast impulse (psi-ms/lb$^{1/3}$)
i_b	Unit blast impulse (psi-ms)
K_x	Total spring constant for soil for horizontal translation (lbs/in)
K_y	Total spring constant for soil for vertical translation (lbs/in)
k_x	Spring constant for soil element for horizontal translation (lbs/in)
k_y	Spring constant for soil element for vertical translation (lbs/in)
L	1) Length of rectangular foundation, in plane of rotation for rocking or in direction of horizontal force (in)
	2) Length, in horizontal direction, of foundation between supports and/or free edges (in or ft)
L_F	1) Length of loaded area of foundation (ft)
	2) Length of foundation extension of cantilever wall barrier (in)
l	Charge location parameter (ft)
l_{cr}	Distance from face of support to critical section for shear for simple type foundation extension (in)

l_n — Clear span to face of support for simple type foundation extension (in)

M_{cr} — Applied unit design load moment at critical section for shear for thick foundation (in-lbs/in)

M_{Fo} — Unit bending moment at face of support for foundation extension of single cell barrier (in-lbs/in)

M_{Fu} — Ultimate unit bending moment capacity of foundation required to develop blast wall (in-lbs/in)

M_{HN} — Ultimate unit negative moment capacity in horizontal direction (in-lbs/in)

M_{HP} — Ultimate unit positive moment capacity in horizontal direction (in-lbs/in)

$M(t)$ — Moment of resultant of blast loads about the z axis at the center of gravity of the structure at time "t" (in-lbs)

M_u — 1) Ultimate unit resisting moment (in-lbs/in)

2) Applied unit design load moment at a section (in-lbs/in)

M_{VN} — Ultimate unit negative moment capacity in vertical direction (in-lbs/in)

M_{VP} — Ultimate unit positive moment capacity in vertical direction (in-lbs/in)

M_{Wu} — Ultimate unit moment capacity of backwall element (in-lbs/in)

m — Mass of structure (lbs-sec^2/in)

N — Blow count from standard penetration test

NS — Number of soil elements used in overturning analysis

P_s — Soil bearing pressure at face of support of simple type foundation extension (psi)

P_{cr} — Soil bearing pressure at critical section for shear for foundation extension (psi)

p_H	Reinforcement ratio in horizontal direction on each face
p_V	Reinforcement ratio in vertical direction on each face
p_u	Ultimate unit internal resistance of foundation extension supported on three or four sides and subjected to a trapezoidal loading (psi)
p_w	Reinforcement ratio equal to A_s/bd
R_A	Normal distance from charge to backwall (ft)
R_h	Horizontal resistance of soil (lbs)
R_v	Vertical resistance of soil (lbs)
R_θ	Moment of horizontal and vertical soil resistance forces about the center of gravity of structure (in-lbs)
R_I, R_{II}	Total internal resistance of Sectors I and II, respectively (lbs)
T_c	Thickness of concrete section (in)
TS	Thickness of foundation slab (in)
TW	Thickness of backwall (in)
t	Time (sec)
t_A	Arrival time of blast wave (sec or ms)
t_o	Duration of positive phase of blast pressure (ms)
u	Horizontal displacement of structure (in)
$\ddot{u}$	Horizontal acceleration of structure (in/sec^2)
$(V_i)_{ST}$	Static deflection under weight of structure at soil element attachment point (in)
V(t)	Resultant of vertical blast loads on structure at time "t" (lbs)

V_t	Design load for foundation extension supported on three or four sides (lbs/in)
V_u	Total applied design shear force at critical section (lbs)
v	Vertical displacement of structure (in)
$\ddot{v}$	Vertical acceleration of structure (in/sec^2)
v_c	Nominal permissible shear stress for concrete (psi)
v_H	Shear stress at critical section for shear, Sector II (psi)
v_V	Shear stress at critical section for shear, Sector I (psi)
W	Charge weight (lbs)
x	Yield line location in horizontal direction (in)
x_i	Horizontal distance from center of gravity of structure to soil element attachment point (in)
y	Yield line location in vertical direction (in)
Z_A	Scaled normal distance from charge to backwall (ft/lb$^{1/3}$)
Z_F	1) Scale normal distance from charge to foundation slab (ft/lb$^{1/3}$)
	2) Minimum scaled distance from charge to foundation (ft/lb$^{1/3}$)
β_x, β_z	Influence coefficients for horizontal and vertical spring constants for soil elements
Δ	Distance between soil elements on foundation (in)
θ	Rotation of structure (deg)
$\ddot{\theta}$	Angular acceleration of structure (rad/sec^2)
μ	Poisson's ratio for soil

σ	Vertical stress in soil (psi)
Φ	Overturning angle (deg)
ϕ	1) Capacity reduction factor
	2) Bar diameter (in)

LIST OF SYMBOLS USED IN INPUT TO COMPUTER PROGRAM

AFACE	Area of loaded surface on structure (in^2)
B	Length of foundation, in plane of rotation for rocking, or in direction of horizontal force (in)
C9	Ratio of foundation thickness to backwall thickness
d_c	Distance between the centroids of the compression and tension reinforcement (in)
E1, E2	Moduli of elasticity of bilinear stress-strain curve for soil (psi)
f_c	1) Friction factor for cohesive soils
	2) Adhesion constant for non-cohesive soils (psf)
f_{ds}	Dynamic design stress for reinforcement (psi)
HAUNH	Width of backwall haunch (in)
HB	Ratio of height of backwall to length of foundation
HW	Height of backwall element (ft)
h	Charge location parameter (ft)
I	Mass moment of inertia of structure ($lb\text{-}sec^2/in$)
IC1	Computer program option parameter
ICA1	Computer program option parameter
i_b	Unit blast impulse (psi-ms)
$(KLM)_u$	Load-mass factor in the ultimate range
L	Length of backwall element (ft)
l	Charge location parameter (ft)
N	Number of blast walls in structure
NFDN	Computer program option parameter
NDEL2	Constant for changing integration time step in overturning analysis computer program

NLOAD	Computer program option parameter
NP	Number of charges
NUMPT	Number of integration time steps skipped between output time stations
NUMTM	Number of integration time steps used in overturning analysis
NVEL	Computer program option parameter
NS	Number of soil elements used in overturning analysis
NWALL	Computer program option parameter
P2/P1	Ratios of initial pressure to final pressure on surface
p_H	Reinforcement ratio in horizontal direction
p_V	Reinforcement ratio in vertical direction
R_A	Normal distance from charge to backwall (ft)
SMTP	Stress at which modulus of bilinear soil stress-strain curve changes (psi)
SSB	Ratio of length of loaded area of foundation to total length of foundation
TASM	Time of arrival of blast wave on structure (sec)
TOLG	Smallest duration of loading produced by any one charge on any surface of the structure (sec)
TW	Thickness of backwall (in)
t_A	Arrival time of blast wave (sec or ms)
t_{AO}	Arrival time plus duration of positive phase of blast pressure (sec)
UVECT(i)	Horizontal or vertical component of unit vector normal to a loaded surface of structure
v_f	Velocity of post failure fragments (in/ms)

W	Charge weight (lbs)
WT	Weight of structure (lbs)
XB	Horizontal distance from center of gravity of structure to rear face of backwall element (in)
XCORD(i)	Horizontal distance from center of gravity of structure to centroid of loaded surface (in)
XR	Horizontal distance from center of gravity of structure to left end of foundation (in)
x	Yield line location in horizontal direction (in)
YB	Vertical distance from center of gravity of structure to top of foundation slab (in)
y	Yield line location in vertical direction (in)
β_x, β_z	Influence coefficients for horizontal and vertical spring constants for soil elements
μ	Poisson's ratio for soil
Σi_b	Summation of unit blast impulses on backwall element (psi-ms)

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